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Sewage Research

STUDIES OF SEWAGE PURIFICATION. XIV. THE ROLE OF SPHAEROTILUS NATANS IN ACTIVATED SLUDGE BULKING*

By C. C. Ruchhoft and John F. Kachmar

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The bulking of activated sludge has received the attention of sanitary engineers and chemists ever since the development of the process to large scale operation. Bulking has been considered the result of several different causes. In a recent excellent paper Heukelekian and Ingols [1] divide bulking into two general classes: carbohydrate bulking and sewage bulking. They studied seven factors that were involved, including oxygen supply, food concentration, sludge concentration, sludge condition, carbon to nitrogen ratio, temperature and nitrates. Bulking, they said, was induced by an excessive development of sludge or certain organisms comprising the sludge, due to the improper balance of food in relation to sludge. These authors stressed aeration rate as an important factor in this phenomenon.

One variety of bulking is commonly associated with excessive growths of *Sphaerotilus natans* When this type of bulking occurs carbohydrates are often found in the sewage influent. Lackey and Wattie,[2] in a previous paper of this series, reviewed instances of activated sludge bulking in which *Sphaerotilus natans* was considered the causative agent, and presented the biology of this organism. The limits of nutrient elements requisite for its growth were determined, and in an extensive search no substance was found, common or apt to occur in sewage, which stimulated the organism to excessive growth. These investigators found *Sphaerotilus natans* to be a strict aerobe. Littman [3] has contributed a study of the carbon and nitrogen transformations of sewage by Sphaerotilus. He found that a concentration of 757 p.p.m. of Sphaerotilus dosed with sterile sewage and aerated, removed a maximum of 56 per cent of the 5-day B.O.D. of the sewage after four hours and also determined the carbon dioxide produced. He concluded that the Sphaerotilus sludge produced had high sludge indices, exerted a moderate purifying action on sewage and that certain types of bulking appeared to be the result of the over-growth of activated sludge by these organisms.

The view that carbohydrates are specific stimulants in inducing bulking is quite common. Ingols and Heukelekian [4] expressed the view

* Presented at the First Annual Convention of the Sewage Works Federation, Chicago, Ill., Oct. 3, 1940.

that glucose stimulates *Sphaerotilus natans* to a greater extent than zoogleal bacteria, even under aerobic conditions. Ingols [5] not only considers *Sphaerotilus natans* as a facultative anaerobe but concludes that *Sphaerotilus natans* grows much more rapidly as the oxygen content decreases. The physiology of both *Sphaerotilus natans* and zoogleal bacteria should be very carefully studied so that our understanding of the causes and cure for Sphaerotilus overgrowths and bulking difficulties will be sound. In this paper, therefore, we have studied the growth and metabolic response of *Sphaerotilus natans* to carbohydrates under aerobic and anaerobic conditions. While to some this may seem far removed from the immediate problem of bulking, such pure culture information seems imperative for a complete understanding of the bulking phenomenon. Following this a series of experiments were performed in which bulking was induced in activated sludge by certain feeding procedures along with Sphaerotilus inoculations.

In previous papers of this series,[6, 7, 8] the similarity of the sewage purification phenomenon by pure culture zoogleal bacteria and by normal activated sludge has been demonstrated. The sewage and glucose metabolism of both pure culture zoogleal sludges and of plant activated sludges have also been studied and reported.[9, 10] It was decided to study *Sphaerotilus natans* sludges in a similar manner to determine any differences in the metabolism of this organism, and to elucidate, if possible, the factors involved in sludge bulking and the accompanying overgrowth of the zoogleal bacteria by Sphaerotilus.

Preliminary Experiments

A number of early experiments were carried out in cooperation with the biological laboratory upon the growth requirements of *Sphaerotilus natans.* These experiments showed that the fungus had difficulty using glucose in a medium containing only glucose and mineral salts. If nitrogenous materials such as peptone, urea, many amino acids, or sterile domestic or synthetic sewage were added the rate of growth and glucose utilization was greatly accelerated. In one such experiment in a medium containing glucose and mineral salts, only 41 p.p.m. out of 1000 p.p.m. of glucose originally present, or 4.1 per cent, were used in 120 hours by a Sphaerotilus culture. With settled sewage, however, the fungus was able to act upon 800 to 900 p.p.m of glucose within 24 to 48 hours after inoculation. These experiments also indicated that the glucose attack by Sphaerotilus was, curiously, more vigorous when freshly inoculated than when concentrations of 200 to 500 p.p.m. of 48- to 72-hour cultures were used. It was also noted in one experiment that lactic acid was produced. However, lactic acid was not always produced in the metabolism of *Sphaerotilus natans,* and whether its production is due to a change in the metabolism under certain conditions, or to a special strain which cannot be differentiated morphologically from the common strains, is unknown at present.

Lackey and Wattie [2] also isolated a number of other fungi having the general macroscopic appearance and characteristics of Sphaerotilus. Experiments with pure cultures of three such strains of fungi indicated that these organisms attack glucose in glucose-sewage media at rates similar to *Sphaerotilus natans*.

First Experiments upon Oxygen Utilization

A number of experiments to determine oxygen utilization rates were made in 1938 and 1939. The methods employed in the previous work upon zoogleal and plant activated sludges were used. Three bottles containing equal concentrations of *Sphaerotilus natans* were prepared. Two of these were dosed with fresh nutrient material and the third, containing the original supernatant, was used as a control. The oxygen utilization was then followed in the control and one of the fed culture bottles, while the liquor in these bottles was aerated by mercury pumps at rates of about 1.2 cu. ft. per hour. The *Sphaerotilus natans* solids and glucose content were followed in the third bottle, this bottle being aerated with compressed air. It was found that while this system of study had been satisfactory for the metabolic study of activated sludge and zoogleal bacteria cultures, it was not satisfactory for *Sphaerotilus natans*. The growth and metabolic rates were different in the bottles aerated by compressed air and by the mercury pump, apparently because of differences in some important factor or factors in the two bottles. A condensed summary of the results obtained in six of these experiments is given in Table I. If the results in this table are studied, they will be found to be somewhat inconsistent. Nevertheless, a num-

Table I.—*Glucose Removal and Oxygen Utilization by Sphaerotilus natans Cultures*
(Results obtained by simultaneous aeration in 3 bottles)

Experiment No.	Initial Values			After 23 Hours of Aeration of Fed Culture		Oxygen Utilized in 23 Hours of Aeration		
	pH	*Sphaerotilus natans* Solids	Glucose	*Sphaerotilus* Solids	Glucose Removed	By Fed Culture	By Control Culture	As Result of Food Added
		P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.
6	6.6	90	503	+148	91	77	19	58
7	6.4	418	1097	+120	527	401	152	249
8	6.0	1304	1040	+468	831	—	241	—
9	6.8	1532	1083	+334	404	390	283	107
10	6.6	1275	1053	−229	853	325	256	69
13	6.8	153	1311	+215	173	207	—	—

ber of interesting observations may be made from them. First, there seems to be no correlation between the initial quantity of *Sphaerotilus natans* and the quantity of glucose attacked or the extent of Sphaerotilus growth during aeration. Second, considering the very high B.O.D. of the feed used in these experiments, the quantity of oxygen

utilized by the fed culture seems to be low, while the quantity used by the control seems rather high. Consequently, the increment of oxygen which was used as a result of the addition of the food appears low. This increment seems to bear no consistent relation to the quantity of glucose acted upon.

It is interesting to compare the quantities of oxygen used by one gram quantities of control zoogleal sludge, activated sludge and *Sphaerotilus natans* sludge as shown below:

OBSERVED OXYGEN UTILIZATION RANGE IN MG. O_2 PER GRAM OF CONTROL SLUDGE IN 24 HOURS

Pure Culture Zoogleal Sludge	Plant Activated Sludge	Pure Culture *Sphaerotilus natans* Sludge
16.4	37.8	185
to	to	to
29.2	177.0	364

The differences in the 24-hour oxygen requirements of these three kinds of control sludges are very striking. The very high values for *Sphaerotilus natans* can undoubtedly be explained by two facts. The first is the much higher B.O.D. of the supernatant remaining in such cultures when developed rapidly in sterile sewage glucose media, and the second is the inability to remove as large a fraction of the supernatant aseptically in such cultures due to the bulkiness and lack of ability of *Sphaerotilus natans* to settle and compact well in the allowable settling period. These experiments indicated that this method of study of *Sphaerotilus natans* metabolism was not satisfactory because of interfering factors which required investigation.

FACTORS AFFECTING THE GROWTH AND METABOLIC ACTIVITIES OF SPHAEROTILUS NATANS

Activated sludge plant operation efficiency is affected by such factors as the rate of aeration, pH, temperature and the D.O. content of the mixed liquor. At present the conditions obtaining in an activated sludge that favor the rapid accumulation of Sphaerotilus and the development of a bulky sludge are not well understood. Information as to the conditions which favor the optimum operation of the metabolic processes of *Sphaerotilus natans* and consequently those which favor the rapid development of Sphaerotilus would be of value in determining the conditions under which bulking is not likely to occur. The previous experiments gave evidence that the above factors also affect the development of *Sphaerotilus natans.* Consequently, their effect upon the growth and metabolic processes of pure cultures of *Sphaerotilus natans* was studied in a series of experiments.

Experimental Procedure in a Study of Growth Factors

The medium which had been found to contain ample quantities of all the nutrient materials for *Sphaerotilus natans* was used in all of these experiments. This medium contained the following materials: Dextrose, 1000 mgm.; peptone, 600 mgm.; meat extract, 200 mgm.; urea, 50 mgm.; Na_2HPO_4, 50 mgm.; NaCl, 15 mgm.; $CaCl_2$, 7 mgm.; $MgSO_4$, 5 mgm.; KCl, 7 mgm.; distilled water to make 1 liter.

Sixteen liter batches of the above medium were prepared and siphoned into each of five 4-liter serum bottles, the pH adjusted to the desired point and the bottles of media sterilized. At the start of each experiment each bottle of medium was inoculated from a thriving 24-hour room temperature culture of Sphaerotilus in similar media. The culture used for inoculation contained from 268 to 1300 p.p.m. of Sphaerotilus when determined as dry suspended solids.

While all plantings were made from pure cultures with sterile pipettes and the precautions used on zoogleal cultures to maintain pure cultures throughout the 24-hour aeration period were used, bacterial infections sometimes occurred. Usually a 50 ml. portion of the culture was used to inoculate each four liter bottle at the beginning of the experiment. Several Sphaerotilus strains were used. All of them were very much alike so far as metabolism was concerned except one strain (S–7), which, unlike the others, produced large quantities of lactic acid from glucose.

Effect of Aeration Rate upon Sphaerotilus natans Growth and Metabolism

Because it had been noticed in earlier work that the aeration rate affected the growth of *Sphaerotilus natans,* this factor was studied first. Experiments to determine whether *Sphaerotilus natans* was capable of anaerobic growth were included. Three experiments were run at room temperature. Fifteen rates of aeration were used varying from 0.00 to 11.8 cu. ft. of air per hour per three liters of culture. The aeration rates were measured at the start and after three to four hours and some variations over the 24-hour period were unavoidable. Of the rates used four were less than 0.2 cu. ft. per hour, three in the range of 0.2 to 0.5 cu. ft. per hour, three between 1.0 and 3.0 cu. ft. per hour, and three greater than 5.0 cu. ft. per hour.

At the start and after 24 hours of aeration examinations were made for bacterial infection, pH, glucose and Sphaerotilus suspended solids. In one experiment total nitrogen determinations were also made. The dissolved oxygen of the aeration mixture was run immediately at the end of each experiment.

The analytical results obtained are given in Table II. These results indicate that most strains of Sphaerotilus utilized glucose and peptone with only a small drop in pH (from 6.9–7.1 at start to 6.4–6.6 after 24 hours). In experiment S–23 with strain S–7, which is the lactic acid producing strain, the pH dropped from 7.2 to 4.6 and affected the re-

TABLE II.—*Effect of Rate of Aeration on the Metabolism of Sphaerotilus natans*

Experiment No.		S-22	S-26	S-22	S-22	S-21	S-22	S-22	S-21	S-23	S-23	S-21	S-23	S-23	S-23	S-21
Rate of aeration, cubic feet per hour		No aeration*	Nitrogen† gas bubbled through pyrogallol	Nitrogen gas†	0.007	0.027	0.14	0.28	0.375	0.48	1.36	2.85	2.90	5.4	11.1	11.8
pH	Initial	6.9	7.0	6.9	6.9	—	6.9	6.9	—	7.2	7.2	—	7.2	7.2	7.2	—
	Final	6.8	—	7.0	6.6	6.4	6.8	6.7	6.4	4.6	4.6	6.7	4.6	4.6	4.4	6.8
P.P.M. of Sphaerotilus Solids	Initial	23.0	1.8	23.0	23.0	4.4	23.0	23.0	4.4	10.0	10.0	4.4	10.0	10.0	10.0	4.4
	Quantity produced in 24 hours	17.0	11.0	61.0	136.0	140.0	385.0	598.0	329.0	147.0	260.0	547.0	511.0	272.0	183.0	452.0
Sphaerotilus increase factor		0.75	5.7	2.6	5.9	32.8	16.7	26.0	75.6	14.7	26.0	125.0	51.1	27.2	18.3	103 0
Glucose attacked in 24 hours in p.p.m. Initial conc. 1000–1100 p.p.m.		0	0	32.0	51.0	203.0	289.0	703.0	682.0	561.0	705.0	917.0‡	691.0	589.0	547.0	543.0
Percentage nitrogen taken up in 24 hours		—	—	—	—	—	—	20.6	—	25.5	28.3	—	27.3	24.2	25.3	—
Mg. glucose attacked per mg. Sphaerotilus solids produced		0	0	0.52	0.37	1.46	0.75	1.17	2.07	3.81	2.71	1.68	1.35	2.16	2.96	1.20
Mg. glucose removed per mg. nitrogen taken up		—	—	—	—	—	—	24.8	—	13.4	15.2	—	15.5	14.8	13.2	—
Dissolved oxygen in substrate after 24 hours—p.p.m.		0.1	0.0	0.05	0.09	0.0	2.91	1.29	2.10	7.40	7.15	3.30	7.00	6.83	6.98	7.60

* Deaerated media in completely filled, stoppered bottles and agitated by end over end rotation at 1 r.p.m.

† The nitrogen gas contained 0.89 per cent by volume of oxygen.

‡ Culture somewhat contaminated with bacteria.

sults obtained. For the non-acid producing strains, as rates of aeration increased from 0.0 to 0.28 cu. ft. per hour, the quantity of Sphaerotilus solids produced increased from 17 to 598 p.p.m., above which rate there was no further definite trend. With the Sphaerotilus "increase factor," that is, the ratio of Sphaerotilus solids at the end to the solids at the start, there was a general rise as the rate of aeration increased to about 3.0 cu. ft. per hour. Above that aeration rate there was no further rise in the "increase factor." The percentage of glucose removed (or attacked) also increased as the rate of aeration increased to about 1.36 cu. ft. per hour, and with greater rates there was a tendency for this percentage to fall slightly. The ratio of the quantity of glucose removed to the Sphaerotilus solids produced increased with the rate of aeration up to a rate of 0.48 cu. ft. per hour; the trend for higher rates being erratic. The maximum percentage of total nitrogen taken up was obtained with an aeration rate of 1.36 cu. ft. per hour. The dissolved oxygen in the aerating cultures after 24 hours increased gradually as the rate of aeration increased to 2 to 3 cu. ft. per hour, above which rate dissolved oxygen values of 6.83 to 7.60 were obtained.

The conclusion is that *Sphaerotilus natans* grows and carries on metabolic processes most efficiently at aeration rates of 0.5 to 3.0 cu. ft. per hour, as evidenced by the highest percentage of glucose removed, the greatest Sphaerotilus increase factors, the maximum total nitrogen uptake and the maximum total nitrogen removed to glucose removed ratio. If the aeration rate of 2.85 cu. ft. per hour of experiment S–21, in which there was considerable bacterial contamination with the probable resultant utilization of oxygen, is omitted from consideration it appears that *Sphaerotilus natans* grew best at aeration rates providing at least 6.0 p.p.m. of dissolved oxygen at the end of the aeration period.

Sphaerotilus can grow and develop appreciably in substrates containing very low quantities, 0.1 to 2.0 p.p.m. of dissolved oxygen. It is significant that in a good medium Sphaerotilus can produce up to 598 p.p.m. of solids and utilize up to 600 to 700 p.p.m. of glucose at the low rates of aeration that are required to maintain these low dissolved oxygen values.

Sphaerotilus Growth in the Absence of Oxygen and when Nitrogen is Used for Agitation

When nitrogen gas from a commercial tank was passed through inoculated media for 24 hours, increases in Sphaerotilus were also observed. In two experiments, 61 and 99 p.p.m. of Sphaerotilus solids were produced and 32 and 144 p.p.m. of glucose were taken up. The data obtained are also given in Table II. Analysis of the nitrogen gas showed oxygen as an impurity to the extent of 1.04 per cent by weight. In another experiment the nitrogen gas was bubbled through a 2-ft. column of alkaline pyrogallol before passing through the Sphaerotilus inoculated medium. In this case a 11 p.p.m. increase in Sphaerotilus

solids was obtained, but no reduction in the glucose was noted in 24 hours. These experiments with nitrogen are interpreted as indicating again the ability of Sphaerotilus to grow at very low oxygen tensions.

To determine whether growth was possible in the absence of any oxygen, a liter bottle of media was aseptically deoxygenated with N_2 gas to a dissolved oxygen content of 0.37 p.p.m. and *Sphaerotilus natans* was inoculated into it. The deaerated inoculated medium was siphoned aseptically to fill completely two sterile one liter pyrex glass-stoppered bottles. The stoppers were inserted and the sterile tinfoil replaced over them. The bottles were then placed in a turning machine and rotated, end over end, one revolution per minute, for 24 hours. One bottle was then removed and sampled for dissolved oxygen, glucose, pH and bacterial determinations. The first bottle was refilled from the second and the rotation was continued for another 48 hours.

The sample after a total of 72 hours was not contaminated and contained only a few small clumps of Sphaerotilus. The dissolved oxygen was 0.00, the pH 7.0 and the glucose content 1056 p.p.m., indicating no change in this constituent. Glucose removal did not occur during either of the periods. The Sphaerotilus solids increased from 23 to 40 p.p.m. during the first 24 hours, indicating a very slight growth but no further growth occurred in the remaining 48 hours. These results indicate that *Sphaerotilus natans* is capable of growing to a slight extent in a good medium at extremely low oxygen tensions but is unable to grow in the absence of oxygen.

Effect of pH upon Sphaerolitus Growth

In these experiments small quantities of 10 per cent H_3PO_4 or 10 per cent NaOH were added to bring the pH to the desired point. The four-liter bottles containing the media were sterilized, and before inoculation the pH was again checked and adjusted if necessary. All bottles were aerated for 24 hours at a rate as nearly 1.0 cu. ft. per hour as it was possible to maintain. Three experiments were run, one with a pH range from 3.0 to 7.0, and two with a range from 7.0 to approximately 10.0.

The analytical results obtained are given in Table III. These data indicate that aeration at a pH below 5 was detrimental to Sphaerotilus growth and metabolism. Glucose and nitrogen uptake was apparently completely stopped. Only 35 to 42 p.p.m. of Sphaerotilus were produced in 24 hours at these pH values. The high D.O. (7.75 to 7.90 p.p.m.) at the end of the experiment indicates that little oxygen was used.

Even at a pH of 6.0 the activity of Sphaerotilus was partially stopped. This is shown by the solids produced, glucose removed and nitrogen uptake data. At this pH, 253 p.p.m. of Sphaerotilus were produced, 495 p.p.m. of glucose were removed and 22 p.p.m. total nitrogen taken up.

The most favorable pH is the range from 6.6 to 9.0 as evidenced by

a Sphaerotilus solids production of 480 to 635 p.p.m., a glucose utilization of 826 to 1040 p.p.m. (71.3 to 90.3 per cent), a total nitrogen uptake of 27.9 to 34.2 p.p.m., and by the highest ratios of glucose used to nitrogen used and solids produced to nitrogen used.

TABLE III.—*Effect of pH of Medium on the Metabolism of Sphaerotilus natans*

Rate of Aeration Cubic Feet per Hour		1.03	0.99	1.10	1.18	1.0	1.0	1.0	1.0	
									First 24 Hrs.	Next 24 Hrs.
pH	Initial	3.90	4.95	6.05	7.05	8.0	9.0	9.6+	9.6+	8.4
	After 24 hrs.	3.85	5.85	5.85	6.45	7.0	7.4	7.4	8.4	6.9
Sphaerotilus Suspended Solids	Initial	16.0	16.0	16.0	32.0	2.2	2.2	2.2	13.0	—
	Amount produced in 24 hrs.	37.0	35.0	253.0	480.0	497.0	585.0	510.0	39.0	—
Glucose attacked—p.p.m. Initial conc. between 1100–1200 p.p.m.		3.0	36.0	495.0	826.0	992.0	993.0	996.0	14.0	578.0
Percentage nitrogen taken up		0.0	2.8	15.7	24.2	25.3	22.7	24.5	0.0	—
Mg. glucose attacked per mg. Sphaerotilus produced		0.081	1.02	1.96	1.72	2.0	1.69	1.75	0.36	—
Mg. glucose used per mg. nitrogen taken up		—	9.0	22.5	34.1	29.0	32.3	30.1	—	—
Mg. Sphaerotilus solids produced per mg. nitrogen taken up		—	8.75	11.5	14.1	14.5	19.0	15.4	—	—
Dissolved oxygen content after 24 hours		7.90	7.75	4.60	0.74	3.50	3.21	2.27	—	—

In one experiment, good growth occurred in a medium with an initial pH of about 9.6 to 10.0 and it was observed that the pH had dropped to 7.4 after 24 hours. In another experiment (last two columns in Table III) with the same initial pH, there was only slight growth in the first 24 hours during which the pH had fallen to only 8.4. In the next 24 hours, however, considerable growth occurred, 578 p.p.m. of glucose were utilized and the pH fell to 6.9. This seems to indicate that pH values between 8.5 and 10.0 have an inhibitory effect, but the organisms are able to produce acid in sufficient quantities to bring the pH to a more favorable pH range for further growth.

EFFECT OF AERATION TEMPERATURE UPON GROWTH OF SPHAEROTILUS

The bottles of medium were prepared as before and each bottle was stored overnight at the temperature at which it was to be aerated. The tests at 10°, 15°, 20° and 37° C. were carried out in incubators at these temperatures. The bottle which was to be aerated at 30° C. was aerated in an alberene stone hood which was maintained at 30° C. by radiation from a muffle furnace. The temperature in the hood varied slightly but remained between 29° and 31° C. most of the time. The aeration rates in this study were approximately 1.0 to 1.2 cu. ft. per hour. The experiments were carried out in the same manner as when aeration rates and pH were being studied.

The results of the temperature experiments are given in Table IV. At 10° C. only very slight growth occurs as shown by the fact that only 8 p.p.m. of *Sphaerotilus natans* were produced and only 17 p.p.m. or 1.5 per cent of glucose were removed in 24 hours. At 15° C. the ability to grow is somewhat better but even at this temperature only 133 p.p.m. of Sphaerotilus solids were produced and 44 p.p.m. of glucose

TABLE IV.—*Effect of Incubation Temperature on the Metabolism of Sphaerotilus*

Incubation Temperature °C.		10	15	20	30	37
Rate of aeration cu. ft. per hour		1.24	1.0	1.0	1.23	1.0
pH	Initial	7.0	7.0	7.0	7.0	7.0
	Final (24 hours)	7.0	6.7	6.0	6.8	5.4
Sphaerotilus Suspended Solids p.p.m.	Initial	8.5	1.8	1.8	8.5	1.8
	Amount produced in 24 hours	8.0	133.0	989.0	708.0	390.0
Glucose removed—p.p.m. in 24 hours		17.0	44.0	633.0	1003.0	533.0
Total nitrogen removed—p.p.m. in 24 hours		0	6.7	20.9	42.9	19.1
Mg. glucose used per mg. solids produced		2.12	0.33	0.64	1.41	1.42
Mg. glucose used per mg. nitrogen used		—	6.56	30.3	23.4	28.9
Dissolved oxygen after 24 hrs.		—	5.96	2.68	—	3.92

were removed. In the two tests at 20° C. 533 and 633 p.p.m. of glucose were removed and 370 and 989 p.p.m. of Sphaerotilus were produced. A drop to pH 5.4 in the first test probably accounts for the low Sphaerotilus yield. The yield of 989 p.p.m. of solids in the second test is higher than the average yield of about 490 p.p.m. for the 14 tests that were run at optimum aeration rates and pH values at 20° C. and at room temperature.

A temperature of 30° C. was most favorable for the growth of *Sphaerotilus natans*. At this temperature about 1000 p.p.m. or over 86 per cent of the glucose was removed and about 700 p.p.m. of Sphaerotilus solids were produced. A fall in the glucose uptake to 437 and 553 p.p.m. and in solids production to 280 and 390 at 37° C. indicates that this temperature is above the optimum for this organism.

SPHAEROTILUS NATANS METABOLISM

In another series of experiments very small quantities of *Sphaerotilus natans* were inoculated into the sterile peptone glucose medium and two bottles were aerated simultaneously at 20° C., one by compressed air and the other by the mercury pump. In the last two of these experiments a small piston pump which was specifically designed for aeration of small quantities of liquids was used in place of compressed air. In the bottle aerated by the mercury pump, pH, glucose content, *Sphaerotilus natans* content, and B.O.D. of the supernatant were determined at the beginning and the end of the experiment, and the quantity of oxygen used was determined at regular intervals. In the bottle in which compressed air or the small piston pump was used for aeration the same determinations were made at intervals but in place of oxygen used the carbon dioxide produced was determined. A summary of the analytical data obtained is given in Table V.

TABLE V.—*Summary of Analytical Data on Growth and Metabolism of Sphaerotilus natans*

For Seven Experiments—24–58 Hour Aeration Periods	Sphaerotilus Solids Produced P.p.m.	Glucose Removed P.p.m.	Oxygen Used P.p.m.	Carbon Dioxide Produced P.p.m.	*L*-Value Removed P.p.m.
Compressed Air Aeration					
Maximum values....	799	931	616*	848	1936‡
Minimum values....	152	197	77	106	136
Mean values.....	387	464	220	303	795
Mercury Pump Aeration					
Maximum values....	544	986	550	756†	959§
Minimum values....	206	292	105	144	146
Mean values.....	332	522	241	332	569

* Oxygen equivalent of CO_2 used.
† CO_2 equivalent of oxygen used.
‡ Data of five experiments only.
§ Data of three experiments only.

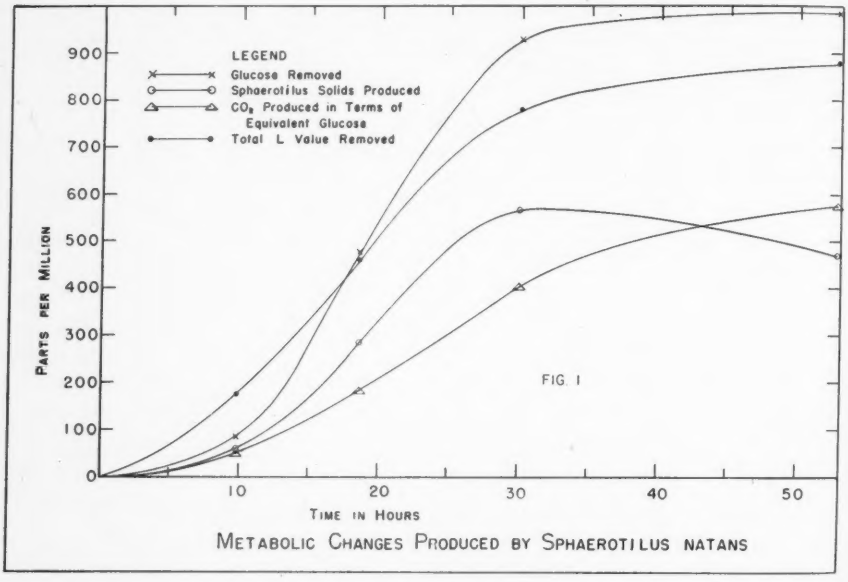
In Experiment 15 the aeration periods were different and checks in the analytical data cannot be expected. The mercury pump aerated cultures usually produced the least *Sphaerotilus natans*. In all of these experiments an average of 322 p.p.m. of Sphaerotilus were produced by them compared to 387 p.p.m. for the compressed air unit. The mercury pump aerated cultures, however, removed an average of 522 p.p.m. of glucose compared to 464 for the compressed air aeration. By calculating oxygen equivalents of the CO_2 produced in the compressed air system the oxygen utilization in the two systems may be compared. Large differences in the quantities of oxygen utilized and CO_2 produced in experiments with the same aeration periods were obtained only in experiments 17 and 20.

TABLE VI.—*Summary of Transformations Produced by Sphaerotilus natans Cultures*

For Seven Experiments—24–58 Hour Aeration Periods	Mg. Glucose Used per Mg. Sphaerotilus Solids Produced	Mg. CO_2 Produced per Mg. Glucose Used	Mg. CO_2 Produced per Mg. Solids Produced	Mg. B.O.D. (*L*-value) Removed per Mg. Solids Produced	Mg. Solids Produced Plus Glucose Equivalent of CO_2 Produced per Mg. Glucose Used
Compressed Air Aeration					
Maximum values..	1.98	1.06*	1.81*	2.42‡	2.04*
Minimum values ..	0.585	0.373	0.296	0.575	0.811
Mean values.....	1.24	0.681	0.930	1.64	1.34
Mercury Pump Aeration					
Maximum values..	3.55	1.264§	2.18§	2.77†	2.24§
Minimum values...	0.535	0.917	0.296	0.709	0.416
Mean values.....	1.75	0.668	1.072	1.97	1.25

* Data of six experiments only.
† Data of three experiments only.
‡ Data of five experiments only.
§ On basis of CO_2 equivalent of oxygen used.

The metabolic changes produced per unit of Sphaerotilus formed are given in Table VI. While the quantity of glucose removed per mg. of Sphaerotilus produced varied considerably in the individual experiments, each result obtained is within the range of these values given in Tables II, III, and IV. In the present experiments from 0.535 to 3.546 mg. of glucose were required per mg. of Sphaerotilus produced while in Table II this ratio varied from 0.37 to 3.81. The mean quantity of glucose used per mg. of Sphaerotilus formed for the mercury pump was 1.752 mg. compared with the mean of 1.242 for the compressed air experiments. Slightly higher L values removed per unit of Sphaerotilus formed (1.969 and 1.636 for the mercury pump and compressed air systems respectively) were obtained as would be expected.



METABOLIC CHANGES PRODUCED BY SPHAEROTILUS NATANS

In these experiments with periods of aeration of 24 hours and longer an average of about 0.67 mg. of CO_2 were produced for each mg. of glucose removed. The quantity of CO_2 produced per mg. of Spaerotilus produced varied from 0.296 to 2.183 mg. with a mean of about 1.0 mg.

It was learned also from Experiments 14, 15 and 16 that more glucose was used per unit of Sphaerotilus produced as the aeration period was increased. With *Sphaerotilus natans* the metabolic activity apparently changes somewhat with the age of the culture resulting in less synthesis and more respiration. No similar evidence of such a change in metabolism could be detected in our earlier studies with zoogleal sludge or plant activated sludge. The growth of *Sphaerotilus natans* and the chemical changes produced in the medium have been plotted in Fig. 1 for Experiment 16 which is considered typical.

Nutritional Experiments with Plant Activated Sludge to Induce Bulking

A series of experiments were carried out with plant activated sludge to study the joint effect of *Sphaerotilus natans* and variations in nutrition in inducing bulking. As these experiments progressed changes in the procedures were made twice so that the experiments are divided into three parts.

Experimental Procedure

Plant sludge was distributed in 8-liter quantities into six 10-liter serum bottles labeled A to F. Bottles A, B, C and D received quantities of pure culture *Sphaerotilus natans* and cotton-filtered domestic sewage every day. In addition, B, C and D received 200, 500 and 1000 p.p.m. of glucose daily, whereas bottle A received no glucose. Bottle E received *Sphaerotilus natans* and 500 p.p.m. of glucose in distilled water but no nitrogenous or mineral material. Bottle F received filtered sewage plus 500 p.p.m. of glucose but no *Sphaerotilus natans*. The above feeding procedure may be outlined as follows:

Bottle Containing Plant Sludge Labeled	Filtered Sewage	Glucose Dose P.p.m.	*Sphaerotilus natans*
A	+	0.0	+
B	+	200.	+
C	+	500.	+
D	+	1000.	+
E	−	500.	+
F	+	500.	−

The analytical work included settling tests, pH, suspended solids and ash determinations. Twice each day, in the morning before feeding and in the afternoon four to five hours after feeding, sludge volumes at 10-minute intervals for a period of one hour were determined. Sludge temperature and pH were recorded at the times the settling tests were made. Suspended solids and ash were determined every morning before feeding, and the sludge index according to Mohlman [11] was calculated. A *sludge looseness index* was also calculated. This we define as the sludge volume of a liter sample after a 10 minute settling period divided by the volume of the supernatant after a 60 minute settling period, or as

$$\frac{\text{10 min. sludge volume}}{1000 - \text{60 min. sludge volume}}.$$

Each morning before feeding the air was turned off and each sludge allowed to settle for one hour after the one liter samples for the settleable solids test had been removed. As much as possible of the supernatant was siphoned off and the feeding procedure and Sphaerotilus inoculation carried out.

Each day a 24- to 48-hour room temperature culture of Sphaerotilus in a glucose peptone medium was used for inoculating the sludge. The eight liter culture was settled and the concentrated solids were apportioned equally into each of the five bottles being inoculated.

After inoculation and feeding each bottle was aerated, at room temperature, at a rate of 3½ to 4 cu. ft. per hour per 6 liters of sludge (the minimum rate that would keep these sludges entirely in suspension). The glucose content of all sludge mixtures was determined three hours after feeding and again in the morning just before the settling, inoculation and feeding procedures were repeated.

The total quantities of *Sphaerotilus natans* solids added to the respective dates in each bottle were as indicated below:

TOTAL SPHAEROTILUS ADDED BY RESPECTIVE DATES

(*Grams, Dry Solids*)

Bottle	6/29	6/30	7/1	7/2	7/3	7/4	7/5	7/6	7/7
A	0.594	1.209	3.381	3.687	4.309	4.655	5.192	5.472	5.788
B	0.594	1.209	3.381	3.687	4.309	4.655	5.192	5.472	5.788
C	0.594	1.209	3.381	2.097	2.719	3.065	3.602	3.882	—
D	0.594	1.209	2.777	2.011	2.357	2.894	—	—	—
E	0.594	1.209	3.381	2.097	2.719	3.065	3.602	—	—
F	None						None		

As indicated above the values for total Sphaerotilus (cumulative) added to the respective dates vary somewhat even though similar inoculations were given to all bottles on each day. Because C, D and E bulked some sludge had to be wasted and the proportion of Sphaerotilus lost in wasting sludge was calculated. The figures do not indicate the quantities of *Sphaerotilus natans* present on these dates. The actual quantities of Sphaerotilus in the sludge could not be determined. However, counts of the Sphaerotilus flocs found per ml. of these sludges were made which indicated definite trends. These trends may be summarized as follows: After inoculation the first day from 1152 to 2816 flocs per ml. were found in these sludges. In sludge A, which received *Sphaerotilus natans* but no sugar, the count dropped after every feeding. In samples B and C, which received 200 and 500 p.p.m. of sugar respectively, no evidence of growth of the *Sphaerotilus natans* was found. In sludges D and E there was evidence that the Sphaerotilus remained viable but at the end of the experiment the number of flocs were no greater than at the start. In sludge F, which received 500 p.p.m. of glucose with sewage, but no Sphaerotilus, very small numbers of Sphaerotilus flocs were found (64 to 128), and there was no tendency for the Sphaerotilus count to increase. The *Sphaerotilus natans* observed in F was present in the original sludge taken from the plant.

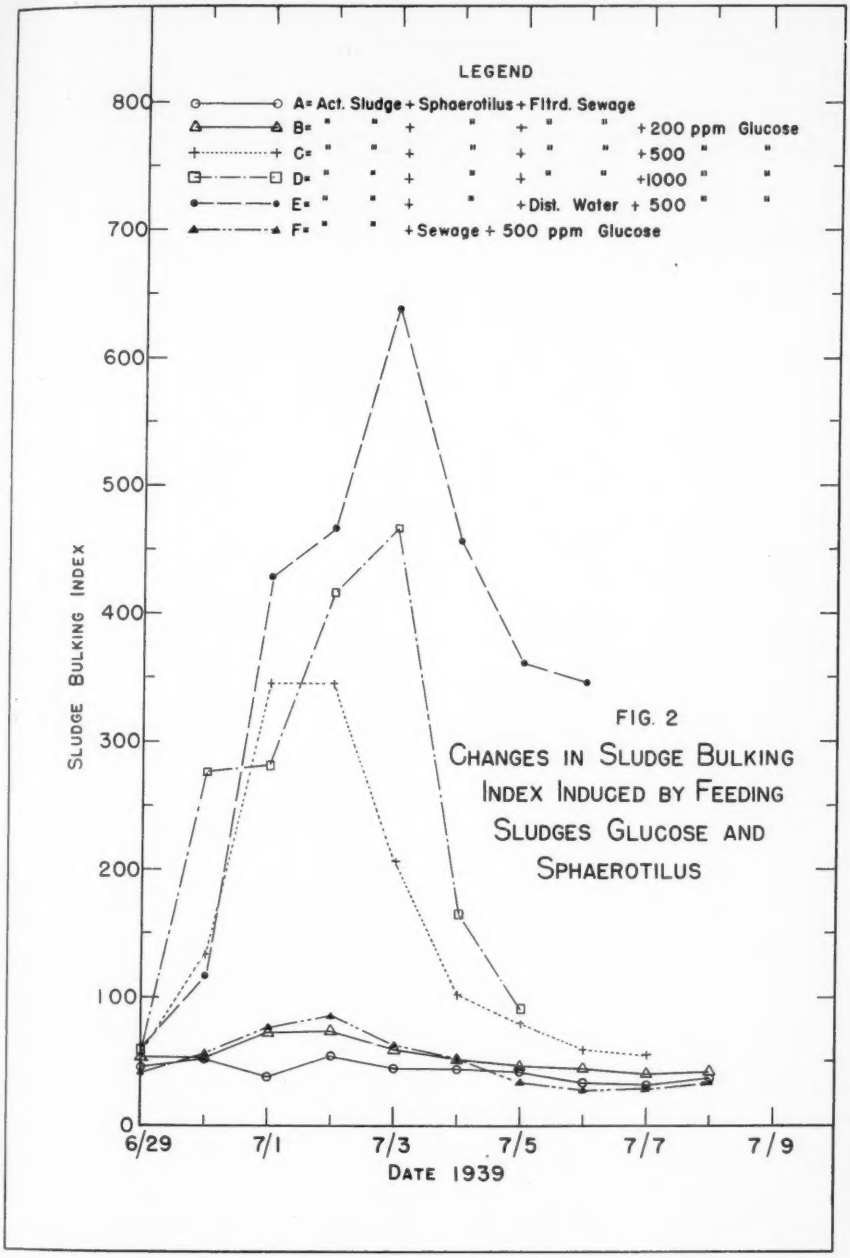


FIG. 2

CHANGES IN SLUDGE BULKING INDEX INDUCED BY FEEDING SLUDGES GLUCOSE AND SPHAEROTILUS

Factors Involved in Bulking

The effect of glucose and *Sphaerotilus natans* in inducing bulking is portrayed in Fig. 2. The graph records the change in sludge indices over the nine day period of this experiment. As indicated by the very low indices for sludge A, Sphaerotilus alone will not induce bulking.

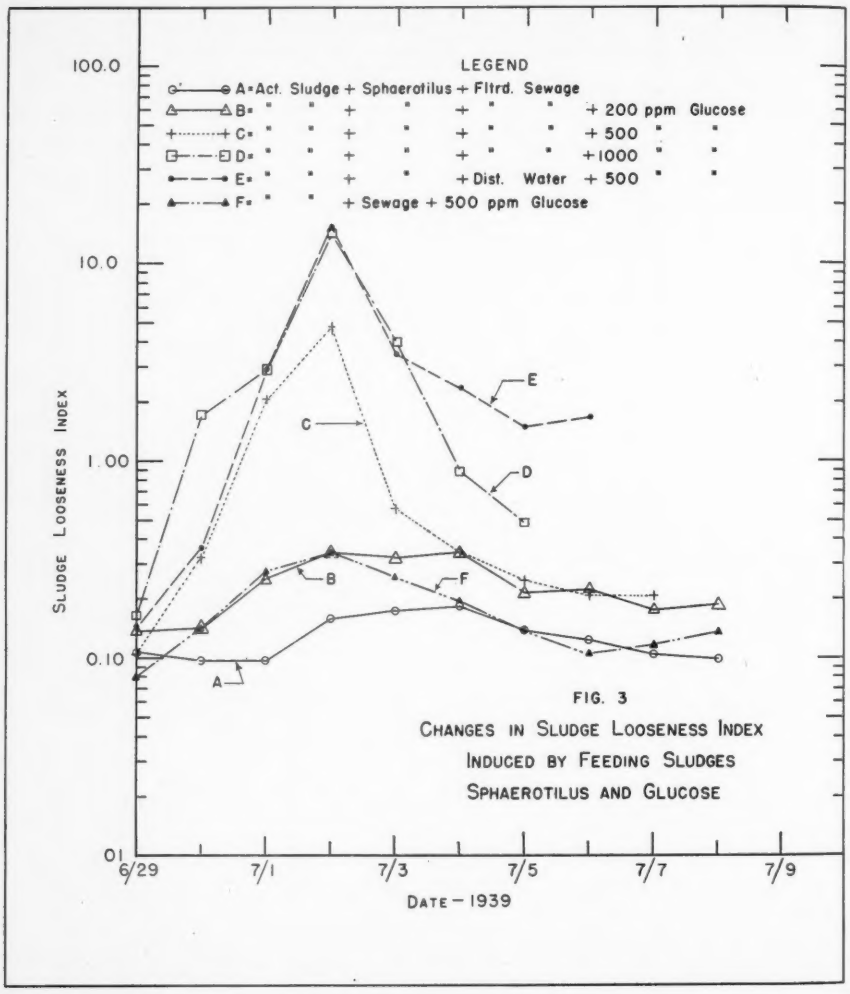


FIG. 3
CHANGES IN SLUDGE LOOSENESS INDEX INDUCED BY FEEDING SLUDGES SPHAEROTILUS AND GLUCOSE

Glucose (when fed jointly with sewage) without Sphaerotilus induced bulking slightly after the second day as indicated by sludge F. After 5 days of feeding with 500 p.p.m. of glucose in sewage, this sludge had completely recovered. *Sphaerotilus natans* and 200 p.p.m. of glucose also induced very slight bulking in B, but recovery occurred after the third day. However, Sphaerotilus and a glucose dose of 500 p.p.m.

with sewage induced immediate bulking in C from which recovery, while slower, did occur after the seventh day. With a glucose dose of 1000 p.p.m. (D) a maximum index of 465 was obtained after the fourth day which then rapidly dropped to less than 100 at the sixth day when the sludge was used for total purification and oxidation tests.

Glucose in distilled water plus Sphaerotilus was the most vigorous vector in inducing bulking. The sludge index of E fed in this manner increased from 50 to 270 the first day and reached a maximum of 640 in 5 days, after which it dropped gradually, but was still above 300 on the seventh day when this procedure was discontinued.

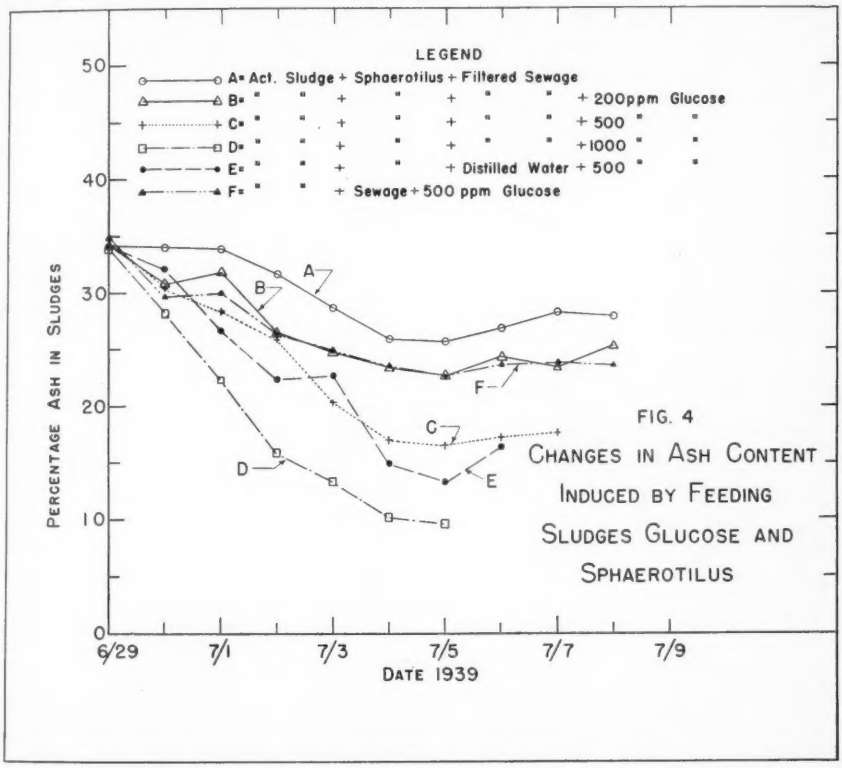


FIG. 4
CHANGES IN ASH CONTENT INDUCED BY FEEDING SLUDGES GLUCOSE AND SPHAEROTILUS

In Fig. 3 the looseness indices for this experiment have been plotted on a log scale with time. This shows the changes involved as effectively as the previous graph. This looseness index seems to be a more sensitive indicator of difference for cases of low sludge index.

The changes in the percentage of ash in the sludge have been plotted in Fig. 4. The low ash content is the result of feeding low ash *Sphaerotilus natans* and glucose.

Unfortunately our data are incomplete in respect to changes in glucose removal rates during the period when bulking was most rapid.

However, in all sludges but E there was a gradual increase in the percentage removed in three hours. By the fifth day, A, B, C and F (A received some glucose with the Sphaerotilus inoculum) were able to remove 90 to 100 per cent of all glucose added in three hours. On the other hand, E, which received no organic nitrogen or minerals for metabolism, deteriorated in its glucose removing ability, the percentage acted on in three hours falling from 30.4 per cent after the first day to 4.3 per cent on the sixth day. Sludge D which received sufficient mineral and nitrogenous material with the glucose, removed 51.9 per cent in three hours even when it was bulking severely.

After nine days of treatment as described above, sludges A, B, and F were each divided between two 10 liter aeration bottles and each pair was treated as previously. One series of bottles designated A_1, B_1, and F_1, were aerated at the previous rate while the second series designated A_2, B_2, and F_2, were aerated at 10 to 11 cu. ft. per hour. All the previous tests were run and this experiment was continued for four days at which time a total of 3.449 grams of Sphaerotilus solids had been added to each of the A and B series bottles. The F bottles received 500 p.p.m. of glucose with sewage daily but no Sphaerotilus. No additional bulking was noted in any of these sludges during this experiment. Increasing the rate of aeration to 10 cu. ft. per hour in the sub 2 series bottles showed no effect upon the sludge indices, but did increase the looseness index of these sludges somewhat.

The Effect of Nutritional Treatment and Bulking Upon the Biochemical Characteristics of the Sludge

After various periods of observation, the sludges receiving Sphaerotilus and varied nutritional treatment as described were taken for determination of their biochemical qualities. The overall purification rate, the oxidation capacity and sludge demand of each sludge were measured. All of these determinations were made as has been previously described.[8] The total purification was determined with sewage alone and also with sewage fortified with 500 p.p.m. of glucose. The oxidizing capacity was determined upon sewage alone. These tests were made upon sludge D after it had been under observation for six days, and similar tests were made upon the other sludges in the following order: E, C, F_2, B_2, and A_2. The data obtained on total or overall purification are given in Table VII and the percentage of L value of domestic sewage removed are plotted in Fig. 5. The previous treatment and bulking had a decided effect in lowering the overall purification for the first 1½ to 3 hours in the cases of sludges C, D, and E, the detrimental effect being greatest for sludges D and E. The L-value removal of sewage plus glucose was still more deteriorated in these sludges for the first 1½ hours, as shown in Fig. 6. This deterioration is again greatest with E. The good sludges A_2, B_2, and F_2, on the other hand, were able to remove the B.O.D. of sewage plus glucose at a slightly greater rate than that of sewage alone.

TABLE VII.—*Differences in Biochemical Characteristics of Sludges Induced by Sphaerotilus and Variations in Feeding Procedure*

Sludge	Days Fed Before Testing	Sludge Index	Suspended Solids Present P.p.m.	Volume of Sewage Feed per Liter of Mixture in Ml.	Nature of Test Feed	Transformation of L-Value						Removal of Glucose					Sludge Demand P.p.m. per Gram Sludge in Indicated Time—Hrs.		
						Percentage Removed Hours				Percentage Oxidized—Hours			Glucose Present Initially P.p.m.	Percentage Removed—Hours					
						1½	3	4½	21	1½	3	4½		1½	3	4½	21	1½	3	4½
D	5	91.8	2776	650	S*	65.7	78.3	83.8	90.1	11.6	19.0	24.2						13.4	23.7	30.5
					S+G†	37.8	78.3	91.9	94.3				680	33.8	—	91	100			
E	6	347	1800	750	S	50.5	74.6	83.1	89.2	4.17	11.2	18.3						15.8	22.0	28.6
					S+G	18.7	35.9	55.5	93.8				647	1.64	20.0	39.6	97.5			
C	7	55.1	3088	780	S	76.6	87.3	91.1	96.2	8.28	11.7	15.5						10.8	15.9	16.5
					S+G	78.2	93.8	94.5	98.7				—	—	—	—	—			
F_2	10	24.8	2620	800	S	81.2	90.3	94.0	98.5	8.57	10.6	16.4						3.47	6.98	11.0
					S+G	89.4	95.5	96.7	99.3				779	90.4	96.4	100	—			
B_2	11	35.8	3638	800	S	82.4	91.8	92.6	97.4	7.29	9.94	24.7						9.52	12.4	17.1
					S+G	90.3	95.0	95.8	98.7				535	80.6	92.5	100	—			
A_2	12	36.4	2608	800	S	77.6	93.3	93.4	97.3	17.8	25.8	33.5						8.63	15.8	19.3
					S+G	88.3	96.7	97.2	98.8				416	96.8	100	—	—			

* Sewage alone.
† Sewage plus 500 p.p.m. glucose.

The decrease in the overall purification performance of sludges D and E is also correlated with a decrease in the ability to attack glucose. Sludges A_2, B_2, and F_2 were able to remove 80 to 96 per cent of the glucose fed them in the sewage plus glucose feed in 1½ hours, and 96 to 100 per cent in 3 hours. Sludge D was able to take up only 39 per cent in 1½ hours while E removed only 1.6 per cent in 1½ hours and 39.6 per cent after 5 hours. As glucose is primarily removed through adsorption and synthesis rather than oxidation,[9, 10] this would indicate that the deterioration in overall purification was not correlated with a reduction in the oxidation performance but rather with a deterioration in the adsorption and synthesis mechanism. The actual values for percentage of L-value oxidized as given in Table VII seem to corroborate this. The data indicate no correlation between the approximately normal oxidation capacities of sludges D and E and their overall B.O.D. purification deterioration.

There are no striking differences in the oxidation capacities of any of the sludges that received *Sphaerotilus natans* and glucose. However, sludge A_2 which received *Sphaerotilus natans* but no glucose seems to be in a class by itself. Upon the basis of percentage of L-value oxidized per gram, sludge A gave values of 6.8, 9.9 and 12.8 per cent in 1½, 3 and 4½ hours respectively. This performance is about double that of the mean for all sludges given regular doses of glucose.

There was a considerable variation in the sludge oxygen demand depending upon the previous treatment. The 4½ hour demand per gram of sludge varied from 11 to 19 mg. for the good sludges A_2, B_2, and F_2. Sludge F_2 which received 500 p.p.m. of glucose daily but no *Sphaerotilus natans* had the lowest demand. This would be expected from the pure culture experiments described earlier. Sludge D which received Sphaerotilus and the largest glucose dose daily, had a (4½ hour) demand of 30.6 mg. per gram, the highest of these sludges. Sludge E, which received the same quantity of glucose as F but in distilled water and also received Sphaerotilus, had a demand under the same conditions of 28.6 or the second highest.

Conditioning of Sludges to Sphaerotilus and Glucose

Sludges A_2 and F_2 from the former experiment were each divided into two portions, A_3, A_4, and F_3, F_4. In addition two bottles of plant sludge, which was bulking somewhat (index 113) but contained little Sphaerotilus, were obtained and labeled P_3 and P_4. The sludges A_3, F_3, and P_3 were fed domestic sewage, and sludges A_4, F_4, and P_4 were fed sewage fortified with 1000 p.p.m. of glucose. Pure culture *Sphaerotilus natans* solids, varying between 0.065 to 0.282 grams, were added to each of the six sludges daily. The experimental procedures employed were identical with those used in the previous series of sludges. This series was carried out for 10 days at which time the following amounts

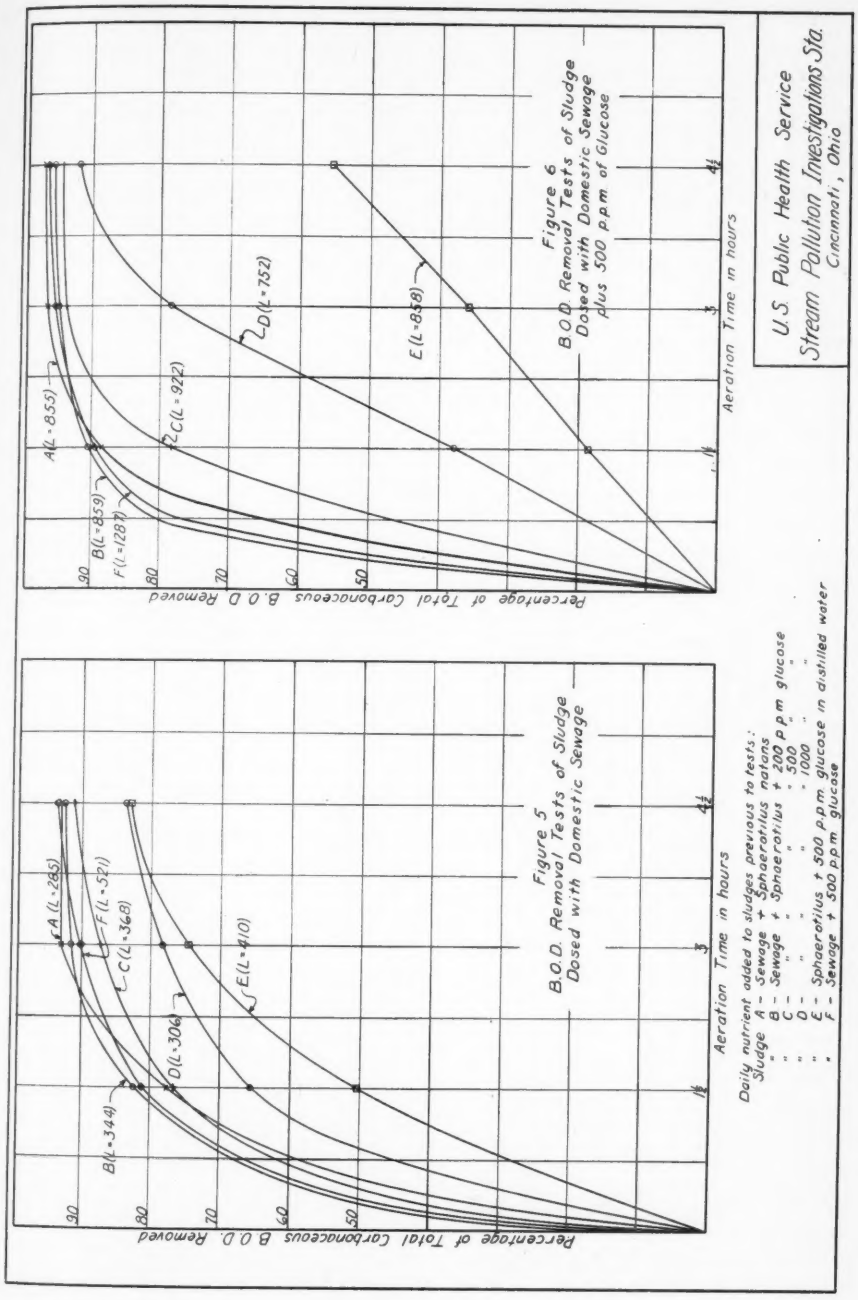


Figure 5
B.O.D. Removal Tests of Sludge
Dosed with Domestic Sewage
Percentage of Total Carbonaceous B.O.D. Removed
Aeration Time in hours
A(L=285)
B(L=344)
C(L=368)
D(L=306)
E(L=410)
F(L=521)
Daily nutrient added to sludges previous to tests:
Sludge A - Sewage + Sphaerotilus natans
" B - Sewage + Sphaerotilus + 200 p.p.m. glucose
" C - " " " " 500 " " "
" D - " " " " 1000 " " "
" E - Sphaerotilus + 500 p.p.m. glucose in distilled water
" F - Sewage + 500 p.p.m. glucose
Figure 6
B.O.D. Removal Tests of Sludge
Dosed with Domestic Sewage
plus 500 p.p.m. of Glucose
Percentage of Total Carbonaceous B.O.D. Removed
Aeration Time in hours
A(L=855)
B(L=859)
C(L=922)
D(L=752)
E(L=858)
F(L=1287)
U.S. Public Health Service
Stream Pollution Investigations Sta.
Cincinnati, Ohio

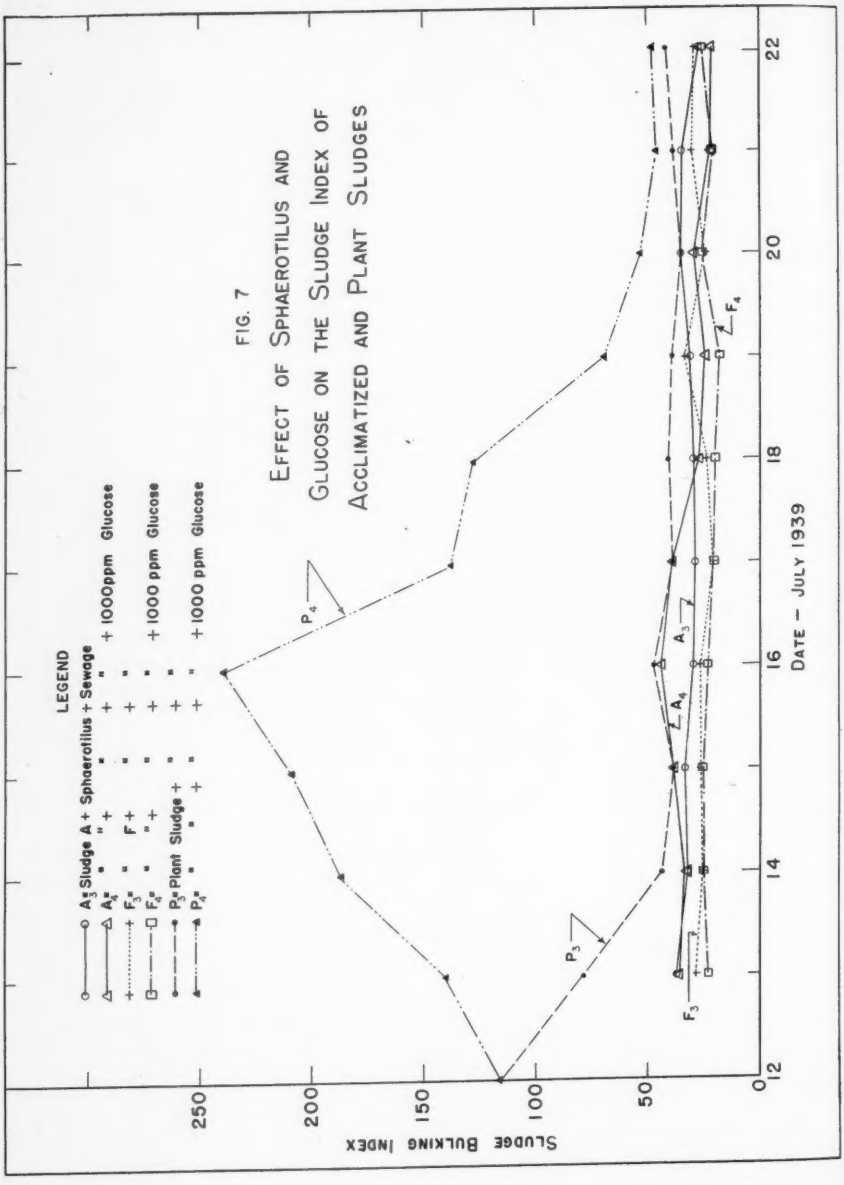

LEGEND
A3 Sludge A + Sphaerotilus + Sewage
A4 " " + " " + 1000ppm Glucose
F3 " F + " "
F4 " " + " " + 1000 ppm Glucose
P3 Plant Sludge + " "
P4 " " + " " + 1000 ppm Glucose
SLUDGE BULKING INDEX
DATE – JULY 1939
P4
P3
A4
A3
F3
F4

FIG. 7

EFFECT OF SPHAEROTILUS AND GLUCOSE ON THE SLUDGE INDEX OF ACCLIMATIZED AND PLANT SLUDGES

of *Sphaerotilus natans* were present in 8 liters of sludge aeration mixture assuming no loss or gain.

A_3	3.229
A_4	1.816
B_3	3.229
B_4	1.816
P_3	1.654
P_4	0.989

The sludge indices obtained during this experiment are plotted in Fig. 7, and the looseness indices are shown in Fig. 8. With the aeration procedure the same as before, apparently sludge A had become acclimated to Sphaerotilus doses and sludge F had become acclimated to glucose. In any case no disturbance in physical characteristics was produced in any of these sludges in this experiment. Sludges A_3, A_4, F_3 and F_4 all had indices under 50 throughout the experiment and the solids content varied from 2300 p.p.m. at the start to 6000 toward the end. In this experiment, therefore, bulking was not induced by Sphaerotilus and 1000 p.p.m. of glucose in sludge A (which had received very little glucose previously), or in sludge F which had received no Sphaerotilus previously.

The plant sludge, however, behaved differently. The sludge as received had an index of about 113, indicating mild bulking. The addition of Sphaerotilus and sewage to P_3 did not further extend bulking but instead the sludge was able to recover and attained an index of 40 or less within two days. However, the addition of Sphaerotilus and glucose with sewage immediately intensified bulking, an index of 240 being reached after four days, which was followed by a gradual recovery.

Though no change was noted in the sludge index, differences in the looseness indices of A_3 and A_4, and F_3 and F_4 occurred in this experiment. The looseness index of A_4 increased for three days and that of F_4 for 6 days. Apparently the looseness index is more sensitive than the common index for slight disturbances in the physical structure of the sludge.

These experiments indicated that neither *Sphaerotilus natans* alone nor glucose alone will induce bulking in a well aerated activated sludge. There may be a slight increase in the sludge index or the looseness index but recovery will be rapid even with continued feeding of glucose or Sphaerotilus with sewage. However, when both Sphaerotilus and glucose are added together to a sludge which has not previously received them, a disturbance of the sludge occurs and bulking is quickly produced, the extent depending upon the amount of glucose added. Gradually over a 5 to 10 day period recovery will take place even with continued application of the Sphaerotilus and glucose. It has been shown that addition of Sphaerotilus to a mildly bulking sludge, well aerated, did not intensify bulking, but was followed by recovery. Also, that a Sphaerotilus or glucose-acclimated sludge, well aerated, was able to take regular applications of both Sphaerotilus and glucose without

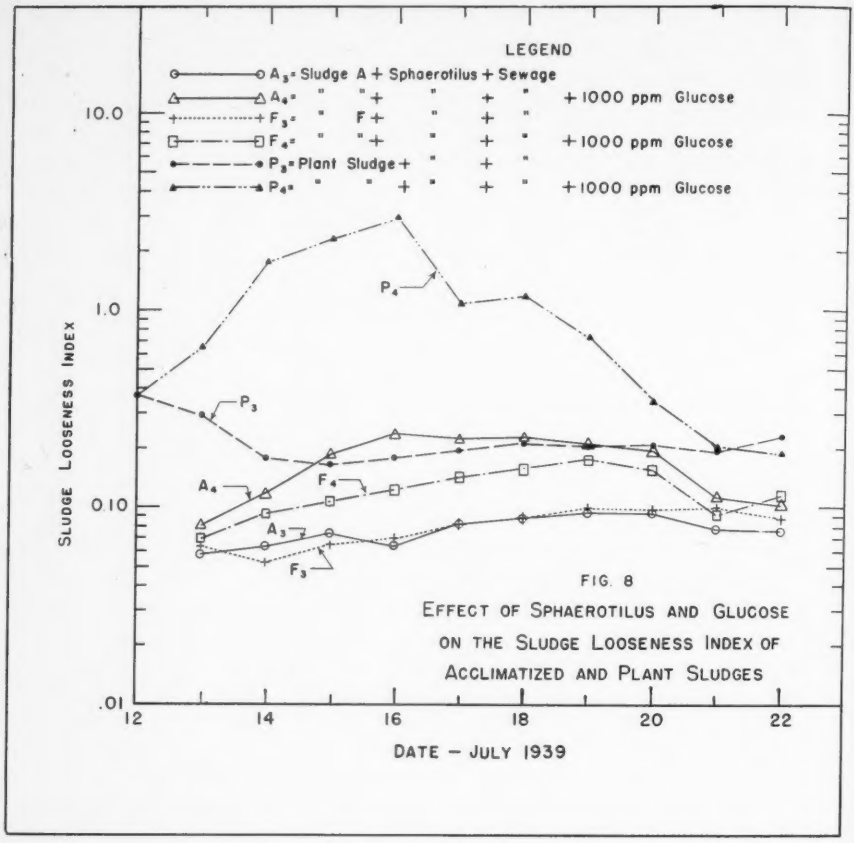


FIG. 8

EFFECT OF SPHAEROTILUS AND GLUCOSE ON THE SLUDGE LOOSENESS INDEX OF ACCLIMATIZED AND PLANT SLUDGES

bulking sufficiently to be detected by changes in sludge index, although a slight increase in the looseness index did occur.

Discussion

It has been shown that *Sphaerotilus natans* grows well in an aerated glucose-peptone medium. Under such favorable conditions from 400 to 700 p.p.m. of fungus solids can be obtained in 24 hours from an inoculum of only a few p.p.m. The medium containing the necessary mineral constituents along with 1000 p.p.m. of glucose and 600 p.p.m. of peptone had an L-value of about double that of a strong domestic sewage. This medium, though designed for the cultivation of Sphaerotilus, was also a very favorable substrate for the growth of zoogleal bacteria, inocula of 10 to 100 p.p.m. producing 440 to 570 p.p.m. of additional solids after 24 hours of aeration.[12] Whereas there were decided variations in the response of different Sphaerotilus cultures to growth in this medium, the response of zoogleal cultures was more consistent. In any case, no evidence was obtained to indicate that the

medium was more favorable to Sphaerotilus growth than to zoogleal growth.

However, several differences were noted in the metabolic activity and physiology of Sphaerotilus and *Zooglea ramigera*. Apparently some strains of Sphaerotilus are capable of producing organic end-products of metabolism, appreciable amounts of lactic acid being produced even with rates of aeration providing oxygen for all metabolic needs. Most strains are not acid producers. However, in several instances a more rapid removal of glucose than of L-value B.O.D. was observed which would indicate the break up of at least a portion of the glucose into simpler products. Zoogleal bacteria, in pure culture or in activated sludge, on the other hand, have never been observed to produce any end products from glucose, when well aerated, other than CO_2 and cellular material.

On the basis of mgs. of glucose acted on per mg. of solids produced in pure culture there is very little difference in the performance of these organisms. These values ranged from 1.74 to 2.94 for zoogleal bacteria [12] and from 1.17 to 3.81 for Sphaerotilus under the same conditions. The variation is greater in this datum for Sphaerotilus than for the zoogleal organisms and this greater variation for Sphaerotilus was noted in all measurements that were made.

The values for mgs. of solids produced per mg. of organic nitrogen taken up were quite different for the two organisms, being 22.5 to 34.1 for *Sphaerotilus natans* and only 5.40 to 6.99 for zoogleal bacteria. From this we might expect the Sphaerotilus to outgrow these bacteria in a medium containing a very limited amount of organic nitrogen. Another important difference is the much greater short time oxygen demand of *Sphaerotilus natans* control sludges compared to control activated sludges or pure culture zoogleal sludges. Finally, the metabolism of Sphaerotilus apparently changes somewhat with the age of the culture, but similar changes have not been observed with cultures of zoogleal bacteria.

The temperature experiments showed Sphaerotilus to have a somewhat narrower optimum growth range than zoogleal bacteria or activated sludge. While the maximum rate of growth occurred at about 30° C., the rate fell off remarkably below 15° C. and was very limited at 10° C. This is undoubtedly the reason for less frequent difficulties with Sphaerotilus during the winter months. The optimum pH range for Sphaerotilus also was found to differ somewhat from normal activated sludge. *Sphaerotilus natans* grew very well over a pH range from 6 to about 9 and was able to remain viable and slowly reduce the pH at values up to about 10. However, it was very sensitive to pH values below 6.0 and growth was practically inhibited at values below 5.0. It appears much more sensitive to pH values below 6.0 than normal activated sludge.

The oxygen requirements of Sphaerotilus is a controversial question. If it were true, as some have claimed, that Sphaerotilus is a facultative anaerobic, it would be logical to assume that this organism

might have a growth advantage over the strictly aerobic zoogleal organisms in activated sludges of zero or very low oxygen content. However, our results indicate very decidedly that *Sphaerotilus natans* can grow only under aerobic conditions and is dependent on oxygen as an hydrogen acceptor. In the total absence of oxygen no growth occurs and no glucose is acted upon. At low oxygen tensions growth of Sphaerotilus and removal of glucose does take place, but at a very low rate. With increasing rates of aeration the quantity of the organism produced increases rapidly, rates of 3 to 5 cu. ft. per hour per 3 liters of medium being optimum. In this respect the behavior of Sphaerotilus is identical with that of the zoogleal organisms. No evidence could be found that indicated that low rates of aeration were more favorable to the growth of Sphaerotilus than higher rates. There is some evidence, however, to indicate that aeration rates in the neighborhood of 10 cu. ft. per hour per 3 liters of medium did hinder Sphaerotilus growth somewhat. Such rates are sufficiently violent to break up the Sphaerotilus flocs and are much higher than any ever met in practice. It may be possible that at extremely low oxygen tensions Sphaerotilus may have some advantage over the zoogleal organisms, but evidence to indicate or disprove this has still to be obtained.

Zoogleal bacteria are quite sturdy organisms in that fairly large variations in environmental conditions such as oxygen tension, pH, temperature, relative ratio of sludge to feed do not appreciably affect their metabolism and their floc properties. However, with extreme and sudden changes there can be expected unfavorable reactions on the part of these organisms toward the change in conditions. Sphaerotilus, on the other hand, is a much more delicate organism, small changes in conditions affecting its metabolism appreciably. This is evidenced by the variations in solids produced, glucose up-take and other data obtained when Sphaerotilus was grown under conditions as nearly identical as possible. In other words, Sphaerotilus will appear in plants in practice only under the most favorable conditions for these organisms. That these are seldom obtained is evidenced by the generally infrequent and temporary appearance of the organism in large quantities.

Because carbohydrates in sewage are a superior food material for the organism, large quantities of Sphaerotilus have always been associated with the sudden appearance of abnormal quantities of carbohydrates in plant influents. Under such conditions bulking has frequently been observed. However, bulking cannot be considered as the direct effect of the Sphaerotilus, although the interweaving of the sludge flocs with the buoyant Sphaerotilus filaments can be a secondary factor in intensifying the bulking effect.

The sudden appearance of carbohydrates acts, in a manner not yet understood, as a shock to the organisms of the activated sludge system. The response to this shock is a biophysical change in floc properties resulting in a light, non-compact, poorly settling floc. It must be understood that bulking and the appearance of Sphaerotilus are both re-

sponses to the same change in conditions which upset the biological equilibrium, in this case the sudden appearance of carbohydrates. Our latter experiments support this conclusion.

The addition of sizable quantities of Sphaerotilus to good, active sludges will not induce bulking. As a matter of fact the Sphaerotilus will generally die out rapidly. Feeding glucose in addition to sewage may or may not induce bulking in a sludge free of Sphaerotilus. Further, sludges containing Sphaerotilus and being fed relatively small quantities of glucose with sewage will bulk slightly, but will immediately recover. Intense bulking will be obtained only when sludges containing Sphaerotilus are either fed sewage with very large quantities of glucose or are fed glucose in distilled water. In this latter case, the feeding of the glucose to the sludge without supplementary nitrogenous materials is such a strong "shocking" agent, that the bulking condition produced is one from which recovery is very slow.

After sludges have been receiving such abnormal food for some time they become acclimatized and a new biological equilibrium is established for this condition. In our case following acclimatization to glucose the sludge was able to receive and react to 1000 p.p.m. of glucose even in the presence of Sphaerotilus without bulking in any manner. That Sphaerotilus is not the direct causative agent of bulking is indicated by the fact that a bulking sludge normally receiving sewage can be fed Sphaerotilus and sewage without glucose and the bulking will gradually disappear.

The induction of bulking in sludges apparently does not affect the oxidizing capacity of the sludge. In other words, bulking is not associated with any change in the physiology of the zoogleal bacteria. However, bulking does seem to be connected with a decrease in the adsorptive power of the sludge and must, therefore, be associated with some change in the physical state of the zoogleal matrix about the bacterial cells.

The sudden appearance of carbohydrates is not necessarily the only possible agency by which activated sludges can be "shocked" into a bulking condition. The majority of the cases of bulking in activated sludges are those not involving the presence of carbohydrates in the sewage. The activated sludge system involves the interaction of three factors—sludge, food and oxygen. A sudden change in the quality of any one or more of these factors may serve to induce bulking in the sludge. Ingols and Heukelekian [4] have shown recently that bulking can be induced in sludges, with reduced aeration rates, by feeding them such materials as proprionate, butyrate, glycerol and even peptone. Hence, glucose is not the only material that may act to give rise to bulking of sludges. Any sudden appreciable change in the form of food material may be expected to "shock" a sludge into a bulking condition.

In their previous paper [1] these same investigators had pointed out several situations productive of bulking in sludges being fed sewage only. They pointed out that with a given sewage and a given sludge concentration, bulking may result from a sudden change in rate of air

supply, particularly if the quantity of air has been appreciably decreased. Also, that with a given sludge concentration and aeration-rate, bulking can be induced by an abnormally strong sewage. They point out that frequent additions of a low B.O.D. sewage will not affect the sludge, but the same total amount of B.O.D. added in the form of a few additions of a very strong sewage will result in bulking. Higher temperatures, accelerating the rate of interaction of sludge, food and oxygen will tend to accentuate the unbalanced condition and hence bulking is encountered more frequently under summer conditions than under winter conditions.

Activated sludges are very efficient agents for the biological purification of sewages and other wastes. After having been developed under given uniform conditions from a given type of influent, the sludges will have developed properties permitting them to handle that sewage most efficiently under those same conditions. If the conditions of plant operation are gradually changed, the sludge is capable of adapting itself to the new conditions. But, if the changes in conditions are sudden and large the sludge undergoes a biophysical strain in meeting this new situation. When this "strain" is severe the properties of the floc are changed and bulking is the result. Consequently, to insure the most efficient operation of a plant the operator must control as far as possible sudden changes in conditions which might upset or strain the sludge. The operator, unfortunately, is usually decidedly limited by plant design to prevent such changes.

In fact, most plants are not designed with sufficient flexibility to enable the plant operator to make proper adjustments when emergency conditions causing bulking arise. At some plants bulking almost always persists indicating a continuous lack of equilibrium in the sludge, sewage and air factors. This shows that a sludge cannot become adjusted to all situations. In such cases the factor causing the continuous "shock" must be found and corrected. No doubt there are constituents in some industrial wastes to which activated sludge would never become conditioned. Wastes containing the simple carbohydrates are not in this class. As shown, with proper food balance and sufficient aeration, activated sludge becomes conditioned to them and recovery from bulking takes place. In these cases a larger quantity of sludge with a lower ash content can be expected than would be obtained from domestic sewage.

We do not believe that there is any reason to differentiate bulking into two classes, carbohydrate—Sphaerotilus bulking and sewage bulking. All bulking conditions that occur in activated sludge arise from a biophysical strain of the sludge due to sudden changes in operating conditions. Some of the vectors capable of producing such strains are now known to a certain extent. Undoubtedly, there are many more not yet discovered or appreciated. Most of the cases of bulking are probably caused by improper plant design and operating conditions. Others are due to the sudden appearance of abnormal materials or abnormal quantities of common materials in sewage. The former cases

can be avoided; the latter can not. But even here, plant operators expecting the abnormal appearance of certain industrial wastes (for example canning wastes) should be on the lookout for them and make changes in operation procedures, if possible, to meet the expected conditions.

Summary

Our strains of *Sphaerotilus natans* were found to be obligate aerobes, being similar to the zoogleal bacteria in this respect. They differed from the zooglea in their greater variability in viability and metabolism. Compared to zoogleal bacteria *Sphaerotilus natans* must be considered a delicate organism because of its sensitivity to variations in environmental factors. Its growth rate in pure culture in a glucose-peptone medium increases with aeration rate to rates considerably higher than those ordinarily used in practice. Its optimum pH range is from 6 to 9 and it is particularly sensitive to pH values below 5. The optimum temperature range is about 30° C. and growth practically ceases at 10° C. even at optimum conditions of other environmental factors.

Experiments to induce bulking indicated that bulking was a response of sludge organisms (zoogleal bacteria and probably others) to a sudden disturbance in biological equilibrium. The three primary factors involved include the sludge, food and rate of oxygen supply. Variations in one or more of these factors may produce the disturbance causing bulking. This disturbance affects primarily the biophysical character of the matrix as indicated by a reduction in short time adsorption capacity and by the formation of a light non-compact floc. The disturbance does not immediately effect the oxidizing capacity of the floc. The phenomenon can therefore best be described as a biophysical response to a sudden change in biological equilibrium. The appearance of *Sphaerotilus natans* is not a primary cause of bulking. The disturbance to which the sludge floc responds to produce bulking in certain instances also produces Sphaerotilus growths. In such cases the interweaving of the *Sphaerotilus natans* filaments with the light floc accentuates the condition.

The authors wish to acknowledge the assistance of J. B. Lackey in obtaining *Sphaerotilus natans* cultures and for Sphaerotilus examinations, of C. T. Butterfield and Elsie Wattie for numerous bacterial examinations, and of Oliver R. Placak and Stephen Megregian for analytical work.

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DISCUSSION OF PAPER BY MR. RUCHHOFT *

By H. Heukelekian and R. S. Ingols

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The material presented in this paper falls within two main parts. The first part deals with a study of some of the factors affecting the metabolism of *Sphaerotilus natans*. The second part deals with some factors influencing the bulking of activated sludge. The authors are to be complimented for undertaking the study of this problem, because information regarding the metabolic requirements of *Sphaerotilus natans* is very meager. A study of this nature could throw considerable light on the probable role played by this organism in activated sludge bulking.

Because of the importance of the nature of the problem studied, the paper has been examined from the standpoint of (1) the validity and adequacy of the experimental evidence and (2) the proper interpretation of the results presented. A thorough discussion of all the points raised in the paper would be too lengthy for the purpose at hand and therefore, only two main points will be discussed at some length: (1) What is the effect of different rates of aeration on *Sphaerotilus natans?* (2) Are the views advanced by Ruchhoft and Kachmar regarding the mechanism of bulking tenable on the basis of the evidence produced by them?

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J.. Dept. Water and Sewage Research, presented at the First Annual Convention of the Sewage Works Federation, Chicago, Ill., Oct. 3, 1940.

The most pertinent problem dealing with the metabolism of *Sphaerotilus natans* is the study of the effect of quantity of air. It is unfortunate that two distinctly different strains of Sphaerotilus were used in determining the effect of various quantities of air within a single experiment (table II). The pH values obtained indicate that one of the strains completes the oxidation of the carbohydrate to carbon dioxide and water without lowering the pH appreciably, while the other strain fails to oxidize the carbohydrate completely, as shown by the production of lactic acid, which lowers the pH value to 4.4 to 4.6. Complete oxidation of carbohydrates is brought about by aerobic organisms under aerobic conditions, while incomplete oxidation of carbohydrates generally takes place under anaerobic conditions. The aerobic strain has been used for the study in the absence of oxygen and low rates of aeration, while the strain which exhibits the anaerobic characteristic was used with high rates of aeration. It appears therefore, that the acid-producing strain was a facultative aerobic organism, because the lactic acid was produced without oxygen, and the organism should be able to grow better or equally well at lower rates of aeration and oxygen tension than the non-acid-producing strain. This acid-producing strain may be similar to the strain studied by Smit (3), which grew better in the absence of air. It seems, therefore, that for a proper interpretation of the results given in table II each strain should be compared separately. This can be done for the aerobic strain at lower rates of aeration. The results show that increasing the air supply from .007 to 0.28 cu. ft. per hour, the growth and sugar decomposition is increased by this strain. The two higher rates of aeration (0.375 and 11.8 cu. ft. per hour) with this aerobic strain show no further advantage. Moreover, when the results in table II are examined as a whole, without separating the two strains, no consistent trend is shown beyond the 0.28 cu. ft. per hour rate. Incidentally, the "Sphaerotilus increase factor" can be misleading in the proper interpretation of the results, since small differences in the quantity of initial inoculation can unduly influence the ratio. It is clear, that the amount of growth produced, irrespective of the initial inoculation should be employed rather than the "Sphaerotilus increase factor." The aerobic strain produced considerable amounts of growth with rates of aeration as low as .027 cu. ft. per hour and with a dissolved oxygen tension of 0 p.p.m. at the end of the aeration period. Even the optimum rate of aeration of 0.28 cu. ft. per hour showed a dissolved oxygen value at the end of the aeration period of only 1.29 p.p.m., with the possibility that it might have been lower during the aeration period.

Our conclusion from table II is that the aerobic strain of Sphaerotilus grows best with 0.28 cu. ft. of air per hour at low dissolved oxygen tensions and that higher rates of aeration do not give additional amount of growth. The authors on the other hand have concluded that *Sphaerotilus natans* grows best with 0.5 to 3.0 cu. ft. of air per hour. We agree with the authors in their statement that even with extremely low rates of aeration Sphaerotilus gives appreciable, though smaller

amounts of growth. We do not agree that the strains employed were all obligate aerobes being similar to zoogleal bacteria in this respect, because one of the two strains used was probably a facultative aerobe. The evidence that Sphaerotilus is as strictly aerobic as zoogleal bacteria cannot be considered adequate, because there is no proof that Sphaerotilus in general, or certain species of Sphaerotilus in particular, cannot tolerate oxygen tensions lower than zoogleal bacteria. The question is not merely academic, but has an important bearing on the bulking problem. If it cannot grow to a greater extent at low oxygen tensions than the zoogleal organisms then it cannot successfully compete with the zoogleal organisms and become the predominant organism under conditions of oxygen deficiency.

However, until more convincing evidence is produced in this respect no final conclusion regarding the mechanism of bulking should be drawn.

Ruchhoft and Kachmar contend that zoogleal organisms are sturdy and capable of withstanding large variations in environmental conditions such as oxygen tension, pH, temperature, relative ratio of sludge to feed, without appreciably affecting their metabolism and floc properties. By contrast Sphaerotilus is pictured to be a more delicate organism. Variations in solids produced, glucose uptake, change in metabolism with age of culture, narrower optimum temperature range of Sphaerotilus are cited as evidence for the delicate nature of the organism. It is argued that it requires a sudden and an extreme change in the environmental conditions to influence the zoogleal organisms, while small changes in environmental conditions effect the metabolism of Sphaerotilus appreciably. The combination of conditions favorable for the growth of Sphaerotilus is said to be seldom realized in plant conditions, explaining the infrequent and temporary appearance of the organisms in large quantities. The widespread distribution of this organism in nature attests to the contrary conclusion. The organism is found in abundance in streams below sewer outfalls, in sewers attached to the walls and in trickling filter slime. In activated sludge it is found very frequently in smaller or larger numbers.

We believe that when sugar is added to sewage it represents more than a minor change in the environment of the organism in the activated sludge process. There are in normal domestic sewage only very small quantities of any material that can yield energy without the uptake of oxygen as is possible with sugar, or which can produce a higher rate of oxygen demand than sugar. Therefore, when this material is added either in laboratory experiments or is received at a plant as a result of intermittent discharge of some industrial wastes, a far-reaching sequence of events takes place in the activated sludge process. The most important of these events is the additional tax on the oxygen supply by the rapid utilization of the available sugar. In certain cases the presence of sugar may tax the available nitrogen supply (2). The use of sugar in conjunction with distilled water in activated sludge feeding experiments does not seem to be justified, because it represents an

artificial and unnatural condition. The rapid initial bulking when sugar is used with distilled water can be due to the utilization of sugar, made possible by the nitrogen originally available in the sludge. After the available nitrogen became exhausted, further dosages of sugar were of no avail, because it could not be utilized in the absence of available nitrogen. The excess sugar behaved as if it were not present and the net effect was one of reaeration of the sludge with a subsequent decrease in the sludge index.

The authors claim that a sludge which has been subjected to a "shock" by the addition of 1000 p.p.m. of glucose becomes "acclimatized" in the course of time and returns to the normal index, even in the presence of Sphaerotilus, after an initial period of bulking. Without resorting to a "shock" and "acclimatization" theory the sequence of events can be explained as follows: (1) Initially the 1000 p.p.m. of glucose is not utilized completely in the 24-hour aeration period; (2) on repeated additions the rate of glucose utilization increases and the sugar disappears long before the end of the aeration period; (3) the period of aeration after the complete utilization of the sugar acts as a period of reaeration, which results in a decrease in the sludge index. Thus the same quantity of sugar may constitute an overdose initially, resulting in bulking and a subsequent underdose, giving rise to recovery of sludge and lower sludge index as a result of the longer period of reaeration. If the dose of sugar had been increased as its rate of utilization increased, so that the organisms were not left without sugar during the aeration period, a decrease in the sludge index would not have occurred.

In experiments with carbohydrate bulking conducted by us a return of the sludge index to normal after initial bulking was not encountered, because the sugar dosages were in the majority of cases 500 to 600 p.p.m. applied three times a day. When smaller quantities of sugar were applied the bulking was not as pronounced and with as low as 25 p.p.m. added three times a day there was no increase in the sludge index. We have also pointed out the importance of the relation between sugar dose and suspended solids content of the sludge. The ratio of sugar added to sludge content must be greater than .25 before sludge will bulk. Relatively high concentrations of sludge were employed in the experiments reported by Ruchhoft and Kachmar, but with only 1000 p.p.m. of sugar applied once a day, so that the sugar-sludge ratio was relatively low.

Readily available carbohydrates such as sugars are not the normal ingredients of sewage. Most of the cases of bulking encountered at sewage treatment plants take place in the absence of such materials. With domestic sewage the activated sludge process is not subjected to a "shock" greater than would be entailed by the variation in the quantity of flow and strength of sewage. The "shock" theory followed by "acclimatization" and recovery fails to explain such cases of bulking. Furthermore, since acclimatization and recovery are a natural consequence of the "shock" the sludge index should return to normal even

if no corrective measures are taken. However, this is not the case. Recovery and return to a normal sludge index takes place only after the operator has removed the cause of the bulking. If bulking were due to the presence of carbohydrates the elimination of them results in improvement and not the continued discharge of the waste into the plant. If bulking has taken place in the absence of carbohydrates, then increasing the air supply and reducing solids concentration usually result in improvement in the condition.

Sludge may bulk in the absence of carbohydrate waste, at intervals, as a result of slow, small accretions of harmful conditions working over a period of time. The intensified symptoms may manifest themselves some time after a period of operation of these factors. Sludge bulking may, on the other hand, be a chronic condition inherent to the specific design of the plant. The shock theory followed by acclimatization and recovery fails to explain such cases of bulking, which are more prevalent than the bulking caused by carbohydrates. A shock ceases to be one when it is continuous. When the shock is continuous it becomes a normal condition to which the organism either adapts itself or dies.

The failure of a sludge to bulk on the addition of large quantities of Sphaerotilus does not necessarily disprove the importance of the role they play. If the conditions favorable for the development of Sphaerotilus are not present, heavy inoculations with Sphaerotilus will not result in an increased sludge index. If, on the other hand, the conditions for their development are favorable, sludge will bulk even without artificial inoculation, since the organisms are universally present in the sludge. Artificial inoculation will only increase the rate of bulking.

It is stated in the paper that bulking is associated with a decrease in the adsorptive power of the sludge. That this is not generally the case can be seen from the common observation that the effluent is usually more sparkling when the sludge is in a bulky condition.

We agree fully that bulking is the result of the interaction of three factors: sludge, food and oxygen. We have already produced experimental evidence to substantiate this view (1).

In conclusion, it is possible that *Sphaerotilus natans* is not a primary cause of bulking. However, the evidence produced in this paper is not sufficient to prove this contention nor adequate to support the view that bulking is a response of zoogleal bacteria to a sudden disturbance of biological equilibrium with a resultant change in the biophysical character of the matrix. Whatever the mechanism of bulking, however, it is definite that bulking is brought about by the improper balance of food, sludge and oxygen.

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REPLY TO THE DISCUSSION BY H. HEUKELEKIAN AND R. S. INGOLS

By C. C. Ruchhoft

In reply to Heukelekian and Ingols' criticism that we employed two kinds of *Sphaerotilus natans,* one an aerobe and one a facultative aerobe, I should like to point out that taxonomists do not classify aerobic and anaerobic organisms in the same genus. It is true that we found evidence of acid end products in the presence of oxygen by one strain. Heukelekian and Ingols assume that the metabolism with the production of acid was in the absence of oxygen. Consequently, we wish to point out again that the acid production took place in the presence of oxygen. In other words, the reaction was an aerobic oxidation of the glucose to lactic acid and not an anaerobic dehydrogenation.

It does seem unusual to have two strains of *Sphaerotilus,* one of which produces complete oxidation of glucose to water and CO_2 and the other only partial oxidation to lactic acid, when both are grown in the same medium under identical aerobic conditions. These strains seem to be identical morphologically but are different physiologically and this metabolic variation certainly invites further investigation.

From the present evidence, however, it cannot be concluded that this acid producing strain is a facultative aerobe, when the growth rate and metabolism of this strain increases with an increase in aeration rate from 0.48 to 2.90 cubic feet per hour as shown.

Heukelekian and Ingols also state that the two strains should be compared separately, which is true, and it may be even better to compare the results of each experiment with each strain separately. Then, in discussing the aerobic strain, they say, "The two higher rates of aeration (0.375 and 11.8 cu. ft. per hour) with this aerobic strain show no further advantage." They apparently overlooked the 2.85 cu. ft. per hour data which gave the highest Sphaerotilus production for this experiment (S–21). The two aerobic strains, acid producing and non-acid producing, gave their highest productivity with initial inocula of 10 p.p.m. or less at aeration rates of 2.90 and 2.85 cu. ft. per hour, respectively. The important fact is that these organisms grow at dissolved oxygen concentrations from 0.1 p.p.m. to practically saturation.

Those who maintain that *Sphaerotilus natans* is an anaerobe must demonstrate growth under anaerobic conditions. While this organism is considered to be cosmopolitan, like most microscopic organisms, there is little evidence for its widespread distribution, particularly in large quantities. It is impossible to identify the organsm visually and, according to Lackey * any one of five different organisms are frequently confused with it. While it has been considered an anaerobe by many without careful examination, it is rarely found or reported in any quantity in Imhoff tanks, either in the settling chamber or in the digestion compartment where true anaerobic conditions prevail.

* J. B. Lackey, private communication (1940).

We are all agreed that bulking is the result of improper balance of sludge with food and oxygen supply. Heukelekian and Ingols disagree with our explanation of the mechanism of bulking when Sphaerotilus is not involved but fail to present a better explanation. There is also disagreement as to whether *Sphaerotilus natans* is a primary or secondary cause of bulking.

We hope, therefore, that this paper and discussion have brought out some new aspects of the bulking phenomenon which will be provocative of further work on the subject so that eventually, while we may not agree as to causes, we will be better able to prevent and control this condition in practice.

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ACTIVATED SLUDGE BULKING*

By H. Heukelekian

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A few fundamental facts regarding the activated sludge process will be helpful for a clearer understanding of the bulking problem.

1. Activated sludge is an aerobic process. The mechanism of this process is completely inhibited under anaerobic conditions and greatly impaired under partially aerobic conditions. Passing air through an aeration tank does not necessarily insure aerobic conditions for several reasons:

(*a*) Low rate of solution of oxygen in sewage.
(*b*) Most of the oxygen passes out into the air unused.
(*c*) The high oxygen demand exerted by the large number of organisms in activated sludge in the presence of food materials.
(*d*) Inefficiency of the spiral flow aeration system with its short circuiting and core formation.

The supply of oxygen adequate at one place may be entirely insufficient at another, due to variations in the strength of sewage, amount and character of sludge carried, design of the tank, type of air diffusers, etc. In addition, even at a given place a supply of oxygen adequate at one time may be inadequate at another time due to some of the above variables as well as differences in temperature.

It is clear therefore that the amount of air supplied is not a reliable criterion of the maintenance of the aerobic conditions. An adequate supply of air may be defined as that amount necessary to meet the demand under the existing conditions leaving some in excess as residual dissolved oxygen. The requisite residual dissolved oxygen level to insure aerobic conditions throughout the sludge floc cannot be definitely stated at present. It is true that in a homogenous system such as in the B.O.D. determination or in surface waters, the oxygen consumption rate is not influenced by the dissolved oxygen level within the normal atmospheric range of oxygen tension. Yet it is conceivable that in a heterogenous system such as in the activated sludge, an oxygen deficiency may exist within the interior of floc while the surrounding water carries small amounts of dissolved oxygen. This is to be attributed to the high rate of oxygen consumption within the floc and the low rate of oxygen diffusion from the surrounding water into the floc. Since the vital seat of activity is within the floc, the oxygen tension in the surrounding water should be high enough to establish an oxygen gradient and provide for the replenishment of oxygen as fast as it is consumed.

* Journal Series Paper, N. J. Agri. Exper. Sta., New Brunswick, N. J., Dept. Water and Sewage Research.

Frequently dissolved oxygen may be entirely absent in the inlet end of the aeration tank due to the high rate of biochemical oxygen utilization. Depending on the length of oxygen deficiency period in the aeration tank, appreciable changes take place in the character of the sludge. Subsequent recovery under aerobic conditions maintained in the latter part of the tank may not be complete. It is also essential that dissolved oxygen should be present at all points in the tank.

2. It can be safely stated that irrespective of whether the initial phase of clarification is brought about by purely physical-chemical or biological agencies, the final stage of purification as well as the initial clarification stage is dependent on the floc produced by the microbiological flora. Since activated sludge is not a pure culture of a single organism, but is composed of a variety of different organisms, it is evident that under certain environmental conditions the proper biological balance may be upset, giving rise to the preponderance of certain organisms and a different type of a floc. The change in the biological balance is due to the fact that there are specific differences of optimum environmental conditions even among closely related organisms. Some of the organisms involved in the activated sludge have been identified, but their specific physiological requirements are not known sufficiently to suppress at all times the activities of the undesirable kinds or to enhance the activities of the more desirable kinds and thereby to increase the efficiency of the process.

3. The activated sludge process is suitable only for wastes in which the concentration of food material is low. When fresh solids are aerated an aerobic decomposition takes place, but a floc similar to activated sludge is not obtained. It is also a matter of general observation that large quantities of organic industrial wastes such as packinghouse, dairy, distillery, and sulfite liquor wastes interfere with the activated sludge process. With high concentrations of food materials bacterial growth consists of cells dispersed in the liquid phase, while food materials in dilute condition are more readily utilized by organisms capable of forming growth aggregates. When food material is too dilute the only possible efficient microbiological process takes place when the food material is localized in certain areas in higher concentration by virtue of surface adsorption. In these localized areas will also be found a large number of micro-organisms It has been observed that when abnormally large quantities of a material like sugar are added to activated sludge not only does the floc become diffuse but the liquor acquires a turbidity chiefly due to the bacterial cells growing in the liquid phase. Dispersion of the cells might also be caused by the anaerobic condition brought about with such overloading.

The above fundamental principles involved in the activated sludge process have an important bearing on the bulking problem because there is an intimate relationship between bulking and the purification mechanism. If the purification mechanism is destroyed by the use of poisons or in the absence of oxygen, bulking will not be noticed. On

the other hand a bulky sludge usually produces the most sparkling effluents. According to our view bulking is a "disease" of the sludge developed in the course of purification of sewage under unfavorable environmental conditions Bulking results when the conditions are not so unfavorable as to destroy the purification mechanism and yet sufficiently unfavorable so as to bring a shift in the delicate biological balance. One of these unfavorable conditions is the inadequate oxygen supply. The inadequacy of the oxygen may be due to any or a combination of diverse factors such as have been discussed above. If activated sludge was formed by a pure culture of a strictly aerobic organism the inadequate supply of oxygen would reflect itself immediately on decreased efficiency of purification. But since there are other organisms present, which probably can tolerate a lower oxygen tension, the actual result of an inadequate oxygen supply is the suppression of the strictly aerobic organisms and the stimulation of organisms with lower oxygen tolerance without an impairment of the purification. Although the evidence is not complete it appears from observations given in the literature that zoogleal organisms are strict aerobes and that *Sphaerotilus* and other filamentous organisms can grow at a lower oxygen tension. When the oxygen supply is ample in relation to the demand, zoogleal organisms thrive; *Sphaerotilus* and other filamentous organisms are small in number and the sludge settles rapidly. When the oxygen supply in relation to the demand becomes inadequate *Sphaerotilus* and other filamentous organisms get the ascendancy and the sludge becomes bulky. Biochemical activities of the latter organisms bring about the purification of sewage in a way similar to the zoogleal organisms except with a lower and more efficient oxygen utilization at the lower tensions. In other words when the sludge is diffuse and filamentous it exposes more surface, which enables the sludge to obtain the limited amount of oxygen present in the medium immediately surrounding it, whereas with a compact sludge the oxygen has to penetrate further into the floc.

The concept of bulking as a "disease" of the sludge suggests the associated idea of an incubation period. Just as in infectious diseases there is a period between the actual infection and the appearance of the symptoms of the disease; the causes of bulking might be operative for a period of time before the actual symptom becomes apparent. When the disease is so advanced as to make the symptoms obvious it takes considerably more effort to cure it. The failure of bulky sludge to respond quickly to a greater air supply does not disprove the contention that an adequate air supply applied at the critical period prior to the "outbreak of the disease" would have been more effective in checking and preventing the bulking. The slow, cumulative type of bulking, naturally applies only to sewage not containing appreciable amounts of industrial wastes. Explosive and sudden types of bulking frequently occur when "shots" of industrial wastes are received. Cause and effect in this type of bulking usually follow each other so closely that it

is not so mysterious as the more subtle and slow changing kind in the absence of industrial wastes. In the latter case causative factors are not so violent but assume an additive and accumulative character over a comparatively long period of time. Let us assume an activated sludge plant which does not receive any industrial waste but which is normally operated without a sufficient safety factor. During the summer months with dry weather flow the strength of sewage increases, the sewage has a high oxygen demand, a lower oxygen saturation value and a higher biochemical oxygen utilization rate. A greater percentage of the oxygen supplied goes to the oxidation of the substrate and a smaller percentage to oxidation of the sludge. The sludge becomes less and less oxidized, therefore exerting a higher demand, thereby taxing the already limited oxygenation capacity. This is only one typical case; other series of circumstances causing bulking could also be cited.

What can the operator do to check bulking? The first maxim is constant vigilance, to keep ahead of the process so that it does not get out of hand making belated measures more or less useless and costly. Daily examination of the sludge with the microscope will be found valuable in determining whether the filamentous organisms are becoming preponderant. Daily dissolved oxygen determinations of the aeration tank contents with particular attention to the inlet end of the tank, will also be useful. Nothing has been said here about the relation of nitrification to bulking but in general the presence of nitrates is an indication of adequate oxygen supply and therefore nitrate determination is desirable. Naturally the determination of the sludge index day by day will aid in showing the tendency toward sludge bulking.

When it is found by means of the above determinations that the sludge has started to become bulky the first remedial measure would be to reduce the amount of sludge carried in the aeration tanks, thereby reducing somewhat the oxygen demand. Simultaneously the quantity of air supplied may be increased. Keeping the sludge in a fresh condition by not allowing it to accumulate in the settling tank for any length of time is always a good practice. Further and more drastic measures such as dilution of the sewage with effluent or surface water, chlorination of the sludge to reduce the high initial rate of oxygen demand may also be found helpful. However, the value of all these remedial measures will be greater the earlier they are attempted. Changes in the basic design of the aeration tanks with the purpose of increasing the efficiency of aeration are beyond the operators' realm but may be necessary before bulking is controlled. Changes which might help are prevention of short circuiting and core formation, selection of proper diffusers, and increasing the air diffusion area in relation to the surface area.

GRAPHICAL ANALYSIS OF THE OXYGEN SAG

By W. E. Howland and F. Farr, Jr.

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In the article of Gordon M. Fair entitled "The Dissolved Oxygen Sag—An Analysis" (*This Journal*, **11**, 445 (May, 1939)) an equation is derived (1*c*) which shows the value of the oxygen deficit for a given section of a stream along which there is no increase in the pollution load and no added dilution. The expression for deficit in this equation can be rearranged so as to consist of two terms each one of which may be plotted as a straight line on semi-log paper. This plotting makes possible a convenient graphical determination of the variation in deficit downstream from any point at which the value of the constants appearing in this equation may be known. At any point along the stream where these constants may suddenly change, as for example at a sewer outfall, a simple recomputation of the constants may be made and new lines readily plotted for the two terms referred to above. Thus this graphical method makes possible the solution of the problem of multiple inlets of sewage or dilution water or multiple changes of reaeration and temperature conditions in the stream.

Equation (1*c*) for oxygen deficit as given by Fair is:

$$D = \frac{k_1 L_a}{k_2 - k_1} (10^{-k_1 t} - 10^{-k_2 t}) + D_a 10^{-k_2 t}, \qquad (1)$$

where

D = oxygen deficit at any point distant a time of flow t from the reference point.

D_a = corresponding value of D at the reference point; *i.e.* where $t = 0$. (Oxygen deficit equals saturation value for dissolved oxygen at the given temperature minus the dissolved oxygen.)

L = the first-stage biochemical oxygen demand of the stream at any point distant a time of flow t from the reference point.

L_a = corresponding value of L at the reference point; *i.e.* where $t = 0$.

k_1 = deoxygenation constant.

k_2 = reaeration constant.

(These constants, k_1 and k_2, appear in the equation as exponents of 10 not of the Napierian base.)

Let $A = \frac{k_1 L_a}{k_2 - k_1}$ and $B = A - D_a$, then equation (1) becomes:

$$D = A10^{-k_1 t} - B10^{-k_2 t} \qquad (2)$$

Each of these two terms plot as a straight line on semi-log paper as shown in Fig. 1. Thus the value of D at any time t from the reference point is the difference between the values of the corresponding ordinates of these two lines. Since $L = L_a 10^{-k_1 t}$ (the unimolecular equation for B.O.D.) and

FIG. 1
GRAPHICAL ANALYSIS OF THE OXYGEN SAG
L = 5 Day, 20°C, B.O.D. in ppm.
D = Oxygen Deficit in ppm.
VALUE OF A AND B AND OXYGEN DEFICIT
DAYS
Critical D = 7.9
Slope = k2 = 0.24
k2 = 0.24
k1 = 0.10
k1 = 0.11
k1 = 0.11
k2 = 0.28
Refer to scale on right
Section 1.
Sewage = 80 epod.
L = 180
D.O.= 0
20°C
Section 2.
Sewage = 100 epod.
L = 300
D.O.= 0
20°C
Section 3.
1.0 cfs. flow
L = 10.0
D.O.= 7.2
20°C
Section 4.
24.5 miles
49.0 miles
49.0 miles
av. v = 1.5'/sec.
av. v = 1.5'/sec.
av. v = 2.0'/sec.
Pop. = 1000
Pop. = 1000
5.0 cfs. = flow
D.O.= 6.2
L = 20.0
D = 3.0
20°C
5.1 cfs. = flow
L = 19.0
D = 5.7
20°C
5.25 cfs. = flow
L = 17.2
D = 7.8
20°C
0.25 cfs. = flow
L = 9.5
D = 5.8
21°C

the ordinate to the lower line on Fig. 1 is $\left(\frac{k_1 L_a}{k_2 - k_1}\right) 10^{-k_1 t}$ then,

$$L = \frac{k_2 - k_1}{k_1} \text{ times the value of this ordinate.} \qquad (3)$$

Correction: "$L = 5D$" in Fig. 1 should be "L = First Stage."

When a sudden change takes place in the conditions along the stream which determine the values of any of the constants entering the above equations, then a sudden shift in the position and/or slope of these lines may be required. The computation of these shifts or changes in the nature of these lines will now be discussed.

The effect of a sudden increase in the B.O.D. of the stream, as caused by a sewer inlet, may readily be computed. The L of the main stream immediately upstream from the sewer inlet is obtained from the ordinate of the lower curve as per equation (3). The value of L immediately downstream from the sewer inlet (which becomes L_a for the new downstream section) is the weighted average of the value of L of the stream above the sewer inlet and the value of L of the sewage. Likewise, the new value of D (which becomes D_a for the new section) is the weighted average of the values of D of this and of the main stream before confluence. When k_2 changes as when the stream suddenly changes velocity or when k_1 and k_2 change with a change in temperature, the values of the ordinates suddenly change because each is dependent on $\frac{k_2 - k_1}{k_1}$. The slopes of the two lines downstream from these points are also affected.

Approximate values of the reaeration constant, k_2, as given by Fair are as follows:

	Value of k_2 at 20° C.
Small ponds and backwaters	0.05–0.1
Sluggish streams and large lakes or impounding reservoirs	0.1 –0.15
Large streams of low velocity	0.15–0.2
Large streams of normal velocity	0.2 –0.3
Swift streams	0.3 –0.5
Rapids and waterfalls	above 0.5

The effect of temperature on k_1 and k_2 can be determined from the well-known equations of Streeter, Phelps, and Theriault:

$$k_{1(T)} = k_{1(20)} \times 1.047^{(T-20)}; \; k_1 \text{ at } 20° \text{ C.} = 0.10$$
$$k_{2(T)} = k_{2(20)} \times 1.0159^{(T-20)}$$

The combination of all these effects is illustrated in the following problem which, it is hoped, will demonstrate the simplicity of the authors' method when applied to a relatively complex problem. Referring to the problem at the bottom of Fig. 1 the following assumptions were made:

1. The flow, B.O.D., dissolved oxygen, and temperature of each inlet and of the main stream immediately above the first inlet.

2. The value of k_1 above the first inlet and the value of k_2 between each section.
3. The distance and average velocity between each section.

Computations

Section 1.

80 g.p.c.d. of sewage = 0.124 c.f.s. for 1000 population.

$$\begin{cases} \text{Oxygen sat. at } 20^\circ \text{ C.} = 9.2 \text{ p.p.m.} \\ D \text{ of sewage} = 9.2 - 0 = 9.2 \text{ p.p.m.} \\ D \text{ of stream} = 9.2 - 6.2 = 3.0 \text{ p.p.m.} \end{cases}$$

$$D_a = \frac{3.0 \times 5.0 + .124 \times 9.2}{5.12} = 3.2 \text{ p.p.m.}$$

$$L_a = \frac{20.0 \times 5.0 + 0.124 \times 180}{5.12} = 24.0 \text{ p.p.m.}$$

$A = .1 \times 24/.14 = 17.1$; $B = 17.1 - 3.2 = 13.9$

Section 2.

Time from reference point up to section 2 $= \dfrac{24.5 \times 5280}{1.5 \times 3600 \times 24} = 1.0$ days.

100 g.p.c.d. of sewage = 0.155 c.f.s. for 1000 population.

D of sewage = 9.2 − 0 = 9.2 p.p.m.

D of the stream at end of one day = 5.7 p.p.m. (taken from plot).

L of the stream at end of one day = 13.6 (read from bottom line) × .14/.1 = 19.0 p.p.m.

$$D_a = \frac{9.2 \times .155 + 5.7 \times 5.1}{5.28} = 5.8 \text{ p.p.m.}$$

$$L_a = \frac{19.0 \times 5.1 + 300 \times .155}{5.28} = 27.3 \text{ p.p.m.}$$

$A = .1 \times 27.3/.14 = 19.5$; $B = 13.7$

Section 3.

Time from reference point up to section 3 $= \dfrac{73.5}{24.5} \times 1.0 = 3.0$ days.

Oxygen sat. at 25° C. = 8.4 p.p.m.

D of inflowing stream = 8.4 − 7.2 = 1.2 p.p.m. (If supersaturated, treat as a negative D).

New temperature of main stream $= \dfrac{25 \times 1.0 + 20 \times 5.255}{6.255} = 21^\circ$ C.

New $k_1 = 0.1 \times 1.047^{(21-20)} = 0.11$.

New $k_2 = .24 \times 1.0159^{(21-20)} = 0.24$

D of main stream at end of three days = 7.8 p.p.m. (taken from plot).

L of main stream at end of three days $= 12.3 \times .14/.1 = 17.2$ p.p.m.

$$D_a = \frac{1.2 \times 1 + 7.8 \times 5.255}{6.28} = 6.8 \text{ p.p.m.}$$

$$L_a = \frac{10 \times 1 + 17.2 \times 5.255}{6.28} = 16.1 \text{ p.p.m.}$$

$A = .11 \times 16.1/.13 = 13.6$; $\quad B = 13.6 - 6.8 = 6.8$

Section 4.

Time from reference point up to section $4 = \frac{122.5}{24.5} \times 1.0 = 5.0$ days.

k_2 changes from 0.24 to 0.28 due to a change in velocity.
$D_a = 5.8$ p.p.m. (value of D at end of five days taken from plot).
$L_a = 8.0 \times .13/.11 = 9.5$ p.p.m. (value of L at end of five days).
$A = 9.5 \times .11/.17 = 6.2$; $B = 6.2 - 5.8 = 0.4$. (If B becomes negative, plot as a positive value and add the ordinates of the two straight lines.)

Conclusions

The graphical method here described consists in essence of the construction of two broken straight lines from which the oxygen deficit is obtained by subtraction of corresponding ordinates. It is convenient (though not necessary) to represent the resulting values of D as a plotted curved line as shown in Fig. 1. Along this line the critical point (at 2.6 days) was readily spotted by eye. This critical value checks favorably with that computed by Fair's equations. It is to be noted that no computations more complex than the evaluation of a simple weighted average were made and no charts such as those appearing in Fair's article were needed. This method can also be adapted to the solution of other problems involving the oxygen sag.

ELECTROLYSIS AT TERMINAL ISLAND*

By G. A. Parkes

During December, 1937, it became necessary to drain the digester at the Terminal Island Sewage Treatment Plant, in the harbor district of the City of Los Angeles, in order to repair the scum breaker arms, which had collapsed on account of heavy accumulations of scum.

The plant had been put in operation in September, 1936, and had been in service about fourteen months. It treats the domestic sewage of San Pedro, Wilmington, and Terminal Island, as well as the industrial waste from two fish canneries in Wilmington. It is believed that the fish waste, high in oil and solids, caused the unusual amount of thick, tenacious scum.

On inspection, it became apparent that excessive corrosion and pitting had occurred on almost all of the metal parts which had been in contact with the sludge, liquor and scum in the tank. In some cases, pitting had penetrated to a depth of 5/16 in. In other areas extensive corrosion had occurred, varying from 1/32 to 1/8 in. Several manhole steps, originally 3/4 in. in diameter, were eaten almost through, as were many of the iron hooks from which the hot water coils were suspended. It was found, however, that many of the steps and hooks and considerable areas of the hot water coils and steel rotating mechanism were unaffected. For example, one side of a structural steel member might be severely attacked and the other side of the same member entirely untouched.

The hot water coils also showed this "spotty" condition, some areas being badly pitted. Subsequent sand blasting, preparatory to painting, apparently perforated the thin places in the pipe at a few points. This was indicated by the presence of small amounts of sludge in the hot water system, when the digester was replaced in operation.

There seemed to be no zoning effect and no portion of the tank seemed to be affected more than any other. The concrete of the tank itself was not damaged in any way nor was there any indication that the reinforcing steel embedded in the concrete had been attacked.

The effects of the corrosion were so serious and had taken place in so short a time, that it was evident that unless the cause were discovered and eliminated, the entire mechanism would soon be destroyed.

Theories

Several theories were advanced as to the cause of the corrosion. Inquiries at the time failed to reveal any similar conditions elsewhere, although some cases of corrosion in digesters have been reported more recently.

* Presented at the Thirteenth Annual Fall Convention of the California Sewage Works Assn., San Diego, Sept. 16, 1940.

The sludge was not altogether normal, due to the presence of the fish waste already mentioned, although the pH had been consistently above 7.0 precluding the possibility of acid corrosion.

Later investigation showed that the sludge and scum were high in ether soluble matter, and extremely high in chlorides. The latter, which was probably due to large quantities of sea water used by the fish canneries, has sometimes amounted to 2000 p.p.m. in the raw sewage entering the plant during the sardine packing season and for some unknown reason is concentrated to as high as 5000 p.p.m., in the sludge in the digester. These figures vary widely and average about one-half the above. These facts, particularly the chlorides, undoubtedly had a bearing on the case, but were not known at the time the corrosion was discovered.

The theory that the corrosion was due to some form of electrolysis seemed to be the most reasonable and while the reconstruction work was going on in the digester, investigations were undertaken to determine the source of electrical current.

Alternating current is used for lighting and for power to operate the digester mechanism but all previous research has shown that such current is rarely, if ever, a cause of electrolytic corrosion.

A well known expert on electrolysis inspected the plant and gave the opinion that the corrosion was caused by stray direct currents from street railway operation. It was found, however, that there are no electric railways on the island and that there is no direct current produced or used in any appreciable amount. Furthermore, the only possible path by which such current could enter the plant was by the city water main. The water service pipe was disconnected and it was found that a higher electrical potential existed in the plant system than in the water main, indicating that the source of current was inside the plant rather than outside of it.

Investigations

At this time, the services of Mr. Otto Wiemer, Electrical Engineer of the Department of Building and Safety, were obtained, who, with the writer, made an extensive series of investigations as to the source of the electrical current.

A complete description of all the investigations would be far too lengthy to be included in this paper. Many experiments and unsuccessful attempts were made to correlate the electrical potentials which were found to exist between the different parts of the plant. Finally a method was decided upon, which for want of a better name, was called the "bench mark" method. This simply consisted of using one point, a conveniently situated water faucet, as a reference point and observing the potentials, *i.e.*, voltages, of all other points in the plant, with reference to this one point. Several hundred readings were made and recorded showing values, positive or negative with reference to the "bench mark."

The equipment used for this work consisted of a very sensitive volt-ammeter, known as Rawson Junior "Multi-meter," with full scale readings in decade arrangements from as low as 2.0 millivolts to 1,000 volts and from 0.1 milliampere to 1.0 ampere, several hundred feet of No. 12 rubber covered wire on a spool and numerous clips and points for making connections.

It should be stated at this point that during the reconstruction of the digester, the plant had been shut down and the contents of the digester transferred to the clarifier and decantation tanks for storage.

It so happened that most of the first readings were made at scattered points throughout the plant and showed only small voltages above or below the "bench mark." However, finally, a series of increasing potentials led to the clarifier, in which digested sludge was stored. Here a difference of 400 millivolts or 0.4 volt was found between various parts of the clarifier piping and steel work and the "bench mark." Similar but lower differences existed between parts of the decantation tanks and the "bench mark."

The investigation was continued and readings made of differences of potential between the "bench mark" and several hundred points throughout the plant. These points included hot and cold water systems, sludge pipes, electrical conduits, exposed metal parts in tanks, reinforcing steel in various structures and even hand rails and the wire fence around the plant property.

The readings varied over a wide range, positive or negative to the "bench mark" but from a study of all the readings, it became evident that greatest differences of potential existed between the point of reference and those tanks in which digested sludge was stored.

The only possible inference which could be drawn from these facts was that, in some manner, not entirely clear, the tanks were acting as huge wet batteries and were actually producing electrical current. This current was leaking out through many inter-connected paths throughout the plant and was returning through other paths to complete the electrical circuit.

In applying this "wet battery" theory to the digester, which was not in use at the time, it was possible to conceive that the corrosion already described could have been caused in this way, provided the corroded parts were "anodic" or positive and some other parts were "cathodic" or negative.

It is well known that when two dissimilar metals are immersed in a proper electrolyte and connected externally, a current will flow from one electrode to the other and that one of the electrodes, the anode, will be eaten away. Such action is usually called galvanic action. It is also well known that it is not necessary to have entirely dissimilar metals, such as copper and zinc, for such a condition to exist. Even electrodes of the same material, such as iron, which by reason of difference in area, surface condition or partial protection, may be dissimilar, will behave in the same manner and one of the electrodes will be eaten away. A number of tests made in the laboratory, using

numerous samples of iron and steel, and sludge liquor for electrolyte, proved that electrolytic corrosion could take place. One test was made with two small grids of black iron baling wire of exactly the same size and shape. One grid was used bare and the other was cast in a plaque of concrete, 1 in. thick. Both grids were immersed in sludge liquor and showed a definite flow of current when externally connected (Fig. 1).

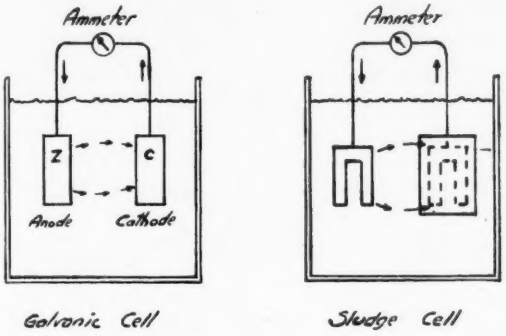

FIG. 1.—Simple galvanic cell.

A model was then constructed to simulate, in principal, the construction of the digester. The model was made of concrete, sixteen inches in diameter and twelve inches high, with walls and bottom two inches thick. A cage of baling wire was cast in the walls and bottom to represent the reinforcing steel, while a coil of wire supported inside the "pot" and in contact with the cage represented the hot water coils. The sludge stirring mechanism was represented by a grid of wire supported in the middle. Several wires were brought out for electrical connections and the "pot" was filled with sludge liquor (Fig. 2).

Readings made with the sensitive voltmeter showed that current flowed through the instrument from the wire cage which was encased in concrete to the grid which was suspended in the liquor. This proved that the "pot" was acting as a battery and that a self-generated current passed from the wire grid anode through the liquor electrolyte to the wire cage in concrete, which was the cathode, and back through an external wire to the anode, thus completing the circuit. Current also probably flowed from the wire which represented the hot water coil to the wire cage and back to the coil through the supporting wire, although this could not be proven.

However, after exposure for about three weeks, with the cage externally connected to the grid, a noticeable amount of corrosion was found to have occurred in the hot water coil wire as well as in the grid.

It was suggested that a possible source of electric current might be the maze of piping which connects the various parts of the plant. These pipes, of various materials, are for the most part, buried in the damp salty sand of the plant site and may, at times, be in brackish ground water.

This theory was based on the well known fact that pipes passing through varying types of soils are subject to electrolytic corrosion. In this case, the pipes buried in the ground would be cathodic while the other ends, being in contact with the sludge in the digester, would be anodic and therefore would be corroded. However, the experiments with the "pot" model, already mentioned, proved that current was produced when the model was standing on a bench and not in contact with the ground.

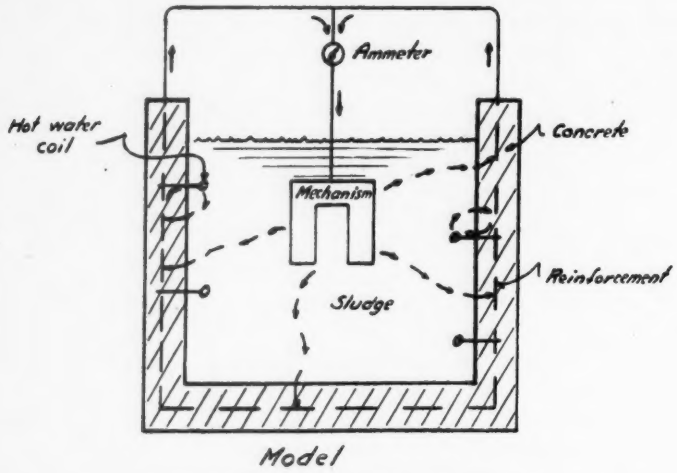

FIG. 2.—Concrete model sludge digester.

A test was made to simulate the condition of the above theory, with the "pot" partly buried in the sand and connected to a quantity of junk iron buried nearby. This sand was well soaked with ground water and conditions of current flow noted. It was found that a small current, probably not over fifteen per cent of the total, was produced by the buried iron and the remainder was produced inside the "pot." It was concluded that, due to the smaller relative area and to faulty electrical contact, the piping system of the plant would deliver but a negligible amount of current to the digester.

ELECTROLYSIS

After a very careful consideration of all the foregoing evidence, it was concluded that the corrosion which had occurred in the digester had been caused by an electrolysis due to a self-generated or galvanic current within the digester itself (Fig. 3).

Further investigation was made to find the cause of the "spotty" condition of the corrosion in the digester, particularly as to why some of the manhole steps and pipe hangers were severely attacked and some were not. It was found by passing a small electric current from a flash-light battery through the various parts, that the steps and

hooks which were corroded were apparently in good contact with the reinforcing steel in the concrete walls of the tank, while those which were not corroded were in bad contact or not in contact at all. This bad contact would prevent the completion of an electrical circuit without which electrolytic corrosion could not occur.

It could only be assumed that the "spotty" condition of structural steel members and some portions of the piping was caused by the fact that some of the original bituminous paint coating adhered to some areas and caused a concentration of current on the unprotected areas.

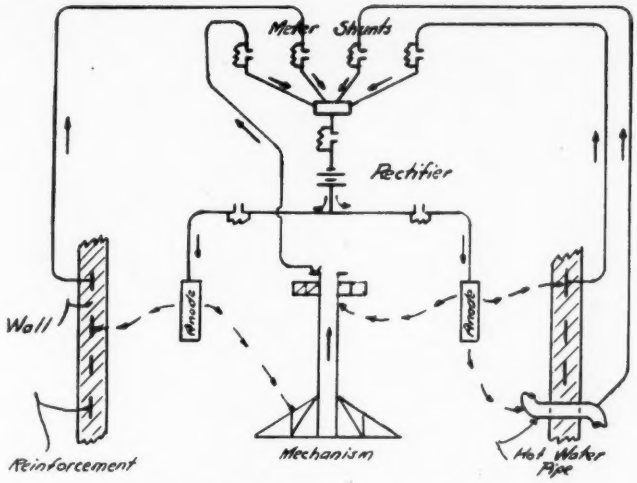

FIG. 3.—Digester showing arrangement of sacrificial anodes.

Considering the digester as a whole, the electrolytic conditions which could have caused the corrosion was now considered as being somewhat as follows:

The hot water pipes, being directly exposed to the sludge and therefore, by reason of their environment, dissimilar from the steel of the reinforcement, acted as anodes. Current flowed through the sludge electrolyte to the cathodic reinforcing steel embedded in the damp concrete and thence back to the pipes through the supporting hooks which were in contact with the steel. The pipes, being anodes, were eaten away.

In the case of the sludge stirring mechanism, the structural steel members were also anodic and current passed through the sludge to the reinforcing steel. This steel, being in contact with the roof of the tank, itself of reinforced concrete with steel beams, passed the current to the rotating sludge mechanism through the driving machinery and thrust bearings, thus completing the circuit. Here again, the steel members of the stirring mechanism, being anodic, were corroded.

While the data obtained in the investigations did not definitely prove that the corrosion had been caused in the manner above stated,

it seemed that all of the facts fitted the theory and that no other theory fitted all of the facts. It was therefore decided to proceed to devise protective measures on this basis.

Protective Measures

At first, an effort to insulate the various parts was considered. This would have been extremely difficult, if not impossible, and at best would have been unreliable, due to the many possible paths for the flow of current. It could not have been accomplished without extensive reconstruction of the tank.

It was decided to sand blast all of the exposed metal in the tank and to cover the parts with a good bituminous coating. After sand blasting, the parts were given a prime coat of Wailes-Dove-Hermiston Corporation's "Bitumastic" solution, followed by two coats of hot "Bitumastic" enamel, mopped on (Fig. 5). This material produces a thick, rather rough and brittle coating but when properly applied gives good protection. Such a coating however, on such surfaces, can not be applied so as to give 100 per cent coverage and it was realized that additional protection by other means would be required.

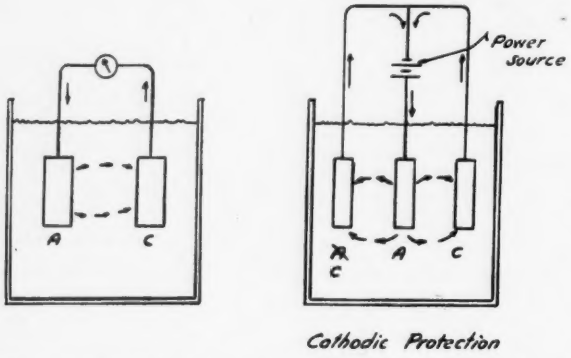

Fig. 4.—Simple galvanic cell after introduction of a sacrificial anode.

After considerable study and inquiry, it was decided to adapt the method known as "cathodic protection" which has for some time been used to protect oil, gas and water pipe lines from corrosion.

This method utilizes the fact that if a metallic surface, which would otherwise be anodic and therefore subject to electrolytic corrosion, be made cathodic by externally applied direct current, that surface can not be corroded and is therefore protected. This method is also sometimes known as "current drainage" (Fig. 4).

In the case of pipe lines, the pipe to be protected is connected by wire to the negative side of some direct current power source, such as a motor generator set or a rectifier unit, the positive side of which is connected to a so called "sacrificial" anode, usually some sort of junk iron. The anode is buried in the ground at some distance from

the pipe. Current coming from the power source, passes first by wire to the anode, even through the ground to the pipe, returning by wire to the source. The pipe thus becomes negative to the anode and the latter is destroyed instead of the pipe. Hence the name "sacrificial." The cost of replacing the junk iron anodes is small as is the cost of power required.

It must be understood that, while theoretically such a method should provide complete protection, due to the numerous uncontrollable factors

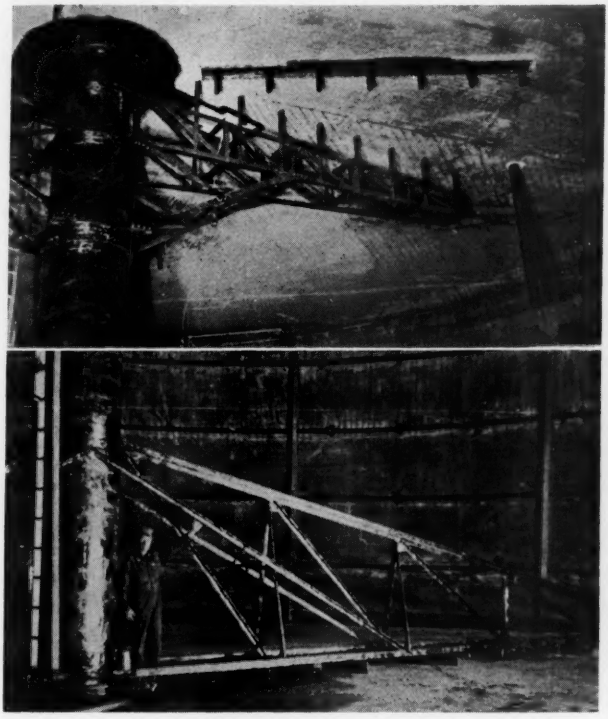

FIG. 5.—Stirring mechanism painted with a bitumastic coating.

encountered in the field, the conditions causing corrosion can only be mitigated to a large extent. In any case, the life of the pipe line is greatly extended and the cost of protection is well worth while.

While there was no precedence to be followed in the case of a sewage digester, it was felt that this method could be used to advantage, and would reduce, if not entirely prevent, the necessity of costly replacements in the near future.

Two anodes were provided, one being hung in each of the two manholes in the roof of the digester. These anodes were steel plates 8 ft. long, 2 ft. wide, and 1/4 in. thick, suspended by two 1 in. diameter iron rods welded to the plates and supported from wooden frames in the

manholes. The iron supporting rods were later found to be badly attacked and were replaced by 2 by 4 in. redwood hangers. The hangers were long enough so that the plates hung vertically in the upper zone of sludge with the tops about 2 ft. below the surface. Heavy copper cables protected with heavy rubber covers were connected to the plates and carried out of the manhole tops and across the roof to the central platform of the digester.

A Westinghouse "Rectox" rectifier, connected to the lighting circuit provided direct current (Fig. 6). The two anode cables were connected to the output or positive terminals of the rectifier. The return or negative terminals were connected to the main bus of a test panel.

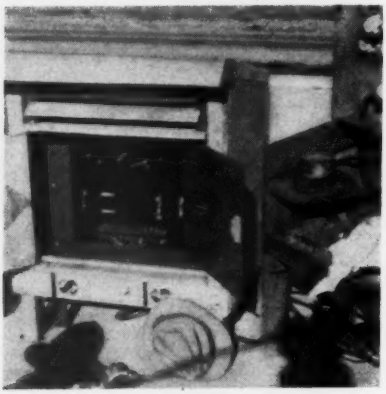

FIG. 6.—Westinghouse "Rextox" copper-oxide type rectifier.

In order to provide for definite return paths for current from the various parts of the tank to be protected, individual wires were connected to these parts and brought to the test panel. Connections were made to the hot water pipes at three points outside the tank, to all sludge and other piping, to the steel beams supporting the roof, to eight points in the steel reinforcement, to the driving machinery and by sliding brush contacts to the upper part of the stirring mechanism. In all, thirty-two such connections were made, each with its individual wire to the test panel.

The test panel consisted of a sheet of "masonite," about 5 ft. high and 30 in. wide, in the center of which a brass bus plate was fastened. Mounted on the panel were thirty-five polarized porcelain receptacles, one for each return wire, one for each anode cable and one on the main return to the rectifier. Each return receptacle was fitted with a homemade shunt, of 3 amp. capacity, across the terminals and on one side was connected to the main bus plate. Each return wire was connected to its respective receptacle. Twenty-five ampere shunts were fitted across each anode cable receptacle and a 50 amp. shunt was fitted across the main return receptacle (Fig. 7).

Two ammeters were provided, each with cords and polarized plugs attached, one ammeter reading to 3 amp. positive or negative, the other reading to 100 amp., positive.

When the apparatus is in operation the circuit is as follows: Current leaving the rectifier passes through the anode shunts to the anode plates. Thence it passes into the sludge and to the hot water coils, stirring mechanism, reinforcing steel and other metal parts. From these parts it goes by the individual return wires to the receptacles on the test panel, and through the shunts to the bus plate. From the bus plate it passes through the main return shunt to the rectifier.

FIG. 7.—Test panel.

The purpose of the shunts is to provide for measuring of the current without interruping the circuit. The anode shunts permit the current passing to each anode to be measured separately. The individual shunts permit measurement of the current returning from each part of the tank to be protected, while the main return shunt provides for measurement of the total current returned and serves as a check on the other readings. The readings on the individual returns permit these circuits to be balanced in approximate proportion to the area to be protected, and also indicate whether the connection is in good condition.

The rectifier has a capacity of 30 amp. at 3.2 volts direct current and is so designed that several combinations of voltage and amperage may be obtained but the tappings which produce 20 amp. at 2.2 volts are used. The total power used is therefore only that used by a medium size electrical light. One-half the current is sent to each anode and the return circuits are balanced to carry from 0.25 to 1.5 amp. each. Readings are made periodically and recorded to note changes. The anodes are hoisted out for inspection from time to time and are replaced as needed.

When removed, the plates are found to be covered with a black honeycombed crust about 2 in. thick, while underneath the crust the

plates are deeply pitted and eaten away at the edges. The wooden hangers are not affected. The crust does not seem to affect the operation of the plate as an anode. One pair of plates, originally weighing 195 lb. each, were found to weigh 90 lb. each, after fourteen months of service. Each plate lost 105 lbs. or 7.5 lb. per month. This equals aproximately 9.0 lb. per amp. per year. It is probable that the anodes should be replaced after nine to twelve months service (Fig. 8).

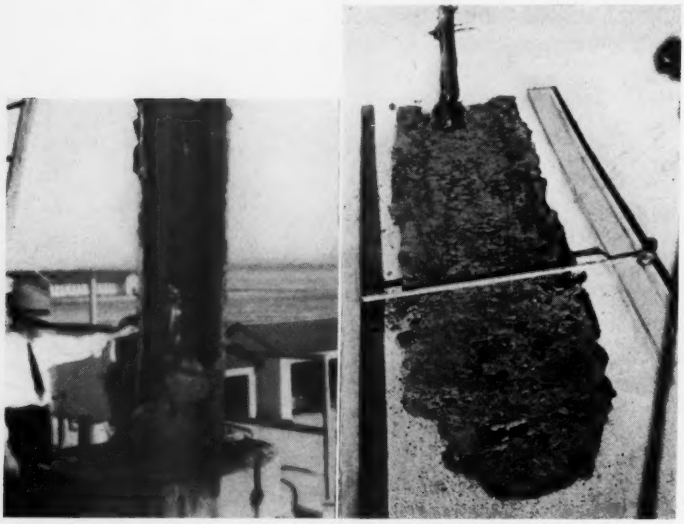

FIG. 8.—Sacrificial anode. Anode after 14 months of service.

COST AND RESULTS

The cost of the installation was about $200 of which $140 was for the Rectox rectifier unit. This cost does not include labor, which was done by the plant operators, under the supervision of the writer.

Most of the electrolysis protection equipment was put in operation about the middle of December, 1938, using a homemade motor-generator set for power supply. The "Rectox" was purchased and installed later.

It is unfortunate that no definite information can be given at this time as to the results of this method of protection, as no opportunity has occurred to make a complete inspection of the interior of the digester. Three things, however, seem to indicate that the protection has been effective.

First, on May 5, 1939, after about five months of operation, an inspection was made of the scum in the digester and the upper part of the scum breaker truss was found to be in excellent condition, the bitumastic coating being intact. This indicated that no serious corrosion was taking place in this part of the mechanism.

Second, a small amount of sludge was noticed in the hot water system soon after the digester was replaced in operation, indicating a small leak. The amount of make-up water required by the system has slowly increased but to date has not reached a serious amount. This is interpreted to mean that the leaks have not greatly increased as would have been the case if electrolytic corrosion had been at work.

Third, it is also felt that if the corrosion had continued at the alarming rate of the first fourteen months, some of the structural parts of the mechanism would have failed entirely in the nearly two years of operation since the protection was installed.

It was gratifying to note that, when for test purposes, the rectifier was shut off, the current in certain of the individual return circuits immediately reversed. This was exactly what was to have been expected from the results of the experiments with the "pot" model, indicating that the conclusions drawn therefrom had been correct.

As to the reason why this particular digester should have been attacked, while many other similar installations have operated for years without trouble, one significant fact stands out. The high chloride content of the sludge, already mentioned, is the only characteristic which differs from normal sludges elsewhere, and which is likely to have any bearing on the case. A saline solution is a good conductor of electricity and would provide a good electrolyte. It is possible, in fact, very likely, that in other plants where digester corrosion has occurred, it will be found that high salinities exist, due to industrial waste, saline ground water infiltration or presence of sea water.

In the near future, it is planned to install new sludge mixing equipment in the digester to convert it into the first stage of a two-stage system, using the decantation tanks as secondaries. When the tank is emptied for this work, a complete inspection will be made. It is hoped that the results of this inspection may be made public at a later date.

The writer is indebted to Mr. Wiemer for his assistance in the field and laboratory and the solution of the problem was in a large measure due to his wide knowledge of the fundamentals of electrolysis and electricity in general. Dr. Richard Pomeroy also gave valuable suggestions and advice.

The plant operators, particularly Mr. Fiscus, Chief Operator, deserve praise for their help and ingenuity in solving many problems of application.

DISCUSSION OF PAPER BY MR. PARKES

By Richard Pomeroy

Research Chemist, Harbor City, Cal.

Electrolysis due to the coupling of two metals is well known to most engineers and others engaged in the mechanical arts. Less generally recognized is the fact that electrolysis also results from differences in solutions. The latter type of corrosion is far more common than the former, and is more important as a cause of corrosion.

The type of solution difference which is most serious is that which exists between aerobic and anaerobic liquids. If a piece of metal is exposed to both aerated water and septic sewage, and the circuit is complete, current will flow from the aerated water to the metal to the septic sewage. This was demonstrated at the Sewage Works Convention in Yosemite in 1935, when a battery was assembled with copper plates, water, and sewage. The current generated by this battery served to run a small motor.

If the metal is corrodable, corrosion will occur at the anaerobic, or anodic, location. This phenomenon is well known in pipe lines, and now we have this example at a sewage treatment plant, so carefully investigated and described by Mr. Parkes.

At the Sewage Works Convention here in San Diego in the spring of 1938, when I discussed this corrosion problem, but without the benefit of the subsequent electrical measurements, I expressed the opinion that the chief cathodic surfaces were on the pipes in the soil about the plant. We are indebted to Mr. Parkes for showing that the reinforcing bars in the concrete may also be effective as cathodes.

Mr. Parkes has attributed the abnormal degree of corrosion in the Terminal Island plant to the high chloride content of the sewage. Undoubtedly this is an important factor, but I believe that an additional condition of significance was the sulfide content of the sludge liquor. Unfortunately no data were obtained on sulfide concentrations, but it is known that they were very high. In all of the other digestion tanks in which corrosion has been recently reported, dissolved sulfides are high, and in one of these cases chlorides are low.

It has generally been supposed that iron in digesting sludge or septic sewage will not corrode if it is isolated so that electrolysis cannot occur. Recent observations have made it appear likely that if sulfide concentrations are high, direct corrosive attack may occur, presumably with evolution of hydrogen. This is especially true if the pH is below 7.0. Evidently both electrolysis and direct corrosive attack must be considered in digestion tanks. We are happy that Mr. Parkes has shown so clearly the significance of electrolysis in one situation, and also the practicability of cathodic protection under such conditions. It may be noted that cathodic protection can be used to prevent or greatly reduce corrosion even if electrolysis is not the cause.

SELF-PURIFICATION OF SEWAGE *

By H. Heukelekian

Associate, Sewage Experiment Station, New Brunswick, N. J.

The phenomenon of self-purification of sewage occurs in nature in streams, lakes, impounding reservoirs, sea, etc. The purification is brought about by physical, chemical and biological agencies entailing sedimentation, oxidation, and reduction processes. These same agencies are utilized in the artificial purification of sewage. Numerous studies have been reported on the extent and nature of the self-purification process in streams, lakes, and reservoirs and artificial purification processes in sewage treatment systems. The purification effected by passing air through sewage has been studied experimentally. In addition to oxidation, which requires long periods of aeration, a certain amount of flocculation is brought about in comparatively short periods of aeration. This principle is made use of in mechanical flocculation and bio-flocculation processes.

However, only a little work has been done on the purification of sewage kept under quiescent conditions for a period longer than that required for the removal of the settleable solids. It has been observed that after the removal of settleable solids, storage of sewage results in the aggregation and settling of the material in a higher state of dispersion.

At the Lawrence Experiment Station [1] in 1919 two outdoor tanks of 17 ft. and 4 in. diameter were used to study self-purification of sewage under quiescent conditions. Each tank was filled to a depth of 2 ft. One was covered with a concrete roof and the other was left open. Within three days green growths and mosquito larvae appeared in the open tanks. No algae grew in the covered tank but mosquito larvae appeared in about half the numbers that were in the open tank. After a week the green growths disappeared in the open tank probably being destroyed by the mosquito larvae. Dissolved oxygen appeared in the open tank in about two weeks and a week later in the covered tank. Average temperature in the open tank was 64–67° F. and in the covered tank 64° F. Sewage in the open tank became stable in six weeks, in the covered tank it took a week longer. No nitrification occurred in either tank.

Whitehead and O'Shaughnessy [3] have reported that self-purification occurs in some of the British sedimentation tanks which are designed for detention periods of 12 to 18 hours. To call attention to the biological nature of self-purification taking place in sedimentation tanks the above named authors added bleaching powder (20 p.p.m.) to the sewage entering a set of sedimentation tanks. A second set of sedimentation tanks were run in parallel without any antiseptics. The ex-

* Jour. Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Water and Sewage Research.

periments were continued for five days; samples of liquor before and after treatment being taken each half hour during that time. With equal periods of detention the oxygen consumed value in 4 hours in the effluent from non-chlorinated tanks was 92.2 p.p.m. and in the chlorinated effluent 107.2 p.p.m. The influent to the tanks had an oxygen consumed value of 107.5 p.p.m.

The work reported in the present paper was undertaken to determine the effect of a long period of storage of sewage on the reduction of B.O.D. The value of such work is not so much in its practical application for sewage treatment works as an additional help in evaluating the self-purification of sewage in streams, lakes and impounding reservoirs. The work serves therefore only as a laboratory confirmation of the results obtained under natural conditions where the various factors could not be so well controlled.

Methods

Sewage was allowed to stand in open battery jars of 5 in. diameter and 7 in. deep with a capacity of one liter. The incubation was at room temperature. At intervals samples were taken for B.O.D. determinations. With the exception of one experiment which will be noted below the samples were taken after shaking the contents of the jar. B.O.D. determinations were made on the samples before and after settling for one half hour and after Seitz filtration.

Results

In the first experiment the B.O.D. removal by prolonged storage of a sample of diluted and undiluted sewage was determined. One part of sewage was diluted with 3 parts of tap water. The samples were removed from the jars in this experiment without prior shaking. The results as given in Table I represent the additive effect of sedimentation and biochemical stabilization. The B.O.D. of the undiluted sewage was reduced from 550 to 260 p.p.m. after quiescent settling for 6 hours,

Table I.—*B.O.D. Values of Sewage Stored Under Quiescent Conditions*

Time Hrs.	Undiluted Sewage			Diluted Sewage *		
	P.p.m.	Reduction Per Cent	Reduction After 6 hrs. Per Cent	P.p.m.	Reduction Per Cent	Reduction After 6 hrs. Per Cent
0	550	—	—	130	—	—
6	260	52.7	—	63	51.5	—
12	240	56.6	8.0	65	50.0	0
24	210	61.8	19.0	55	58.0	12.7
48	110	80.0	58.0	15	88.5	76.2
72	55	90.0	80.0	10	92.0	84.1
120	50	91.0	80.0	10	92.0	84.1

* Diluted 1 : 4 with tap water.

which is equivalent to 52.7 per cent reduction. In six hours the settleable solids were completely removed but further reductions in the B.O.D. were obtained with longer storage periods. If these further reductions are computed on the basis of the B.O.D. remaining after the first 6 hours (260 p.p.m.) the additional reductions amounted to 19 per cent in 18 hours and 58 per cent in 48 hours. For the diluted sewage the corresponding values were 12.7 per cent and 72.2 per cent. B.O.D. values of 55 and 10 p.p.m. were obtained in 72 hours for the undiluted and diluted sewages, respectively.

In the next experiment a sample of medium strength sewage was stored at room temperature for a period of 96 hours under quiescent conditions. Representative samples were taken after shaking the contents of the jar and B.O.D. determinations were made on non-settled, settled and Seitz filtered portions. The results are given in Table II.

TABLE II.—*B.O.D. Values of Sewage Stored Under Quiescent Conditions*

Time Hrs.	Not Settled	Settled		Seitz Filtered	
	P.p.m.	P.p.m.	Reduction After 6 Hours Per Cent	P.p.m.	Reduction After 6 Hours Per Cent
0	150	—	—	95	—
6	165	125	—	85	—
12	175	105	16	125	—
24	120	75	40	60	37
48	120	45	64	50	50
72	115	35	72	40	58
96	95	25	80	30	68

B.O.D. reductions were low in the non-settled samples. During the first 6 to 12 hours the B.O.D. of the stored sewage was higher than the original. Thereafter the B.O.D. decreased below the original value until a 55 p.p.m. reduction was obtained after 96 hours. This reduction in B.O.D. is caused by biochemical stabilization. In addition to it there was a decrease of 25 p.p.m. of B.O.D. due to removal of settleable solids. The B.O.D. due to non-settleable solids decreased from 125 p.p.m. to 25 p.p.m. after 96 hours storage. Fifty-five p.p.m. of this reduction was due to biochemical stabilization and the balance of 45 p.p.m. was due to bioflocculation. The soluble fraction of sewage represented by B.O.D. values of Seitz filtered portion of sewage was reduced by 65 p.p.m during 96 hours storage. Therefore, of 100 p.p.m. reduction in B.O.D. of non-settleable fraction 65 p.p.m. is represented by the B.O.D. of the materials in a high state of dispersion and in solution. The reduction of the soluble portion is also caused by biochemical stabilization and bioflocculation.

In the next experiment a strong domestic sewage was divided into three portions, one was kept in open battery jars, a second portion was kept in stoppered bottles, and a third portion was kept in open jars filled

with broken pieces of glass. Initially and also after 24, 48 and 72 hours the contents of the jars were shaken and a representative sample taken. On one portion of the sample B.O.D. determinations were made on the sewage containing the settleable solids; on a second portion B.O.D. determinations were made after settling for one-half hour and on a third portion after settling and Seitz filtration. The results are given in Table III. The removal of B.O.D. was not as great in the closed vessel as in the open. There was only a slight reduction of B.O.D. in the settled and filtered portions of the sewage during storage in the closed bottles. Increasing the contact surface by the addition of broken pieces of glass did not increase the rate of B.O.D. reduction.

TABLE III.—*B.O.D. Values of Sewage Stored Under Quiescent Conditions*

Time Hrs.	Open Battery Jars			Closed Bottles			Open Jars With Broken Glass	
	Not Settled P.p.m.	Settled P.p.m.	Filtered P.p.m.	Not Settled P.p.m.	Settled P.p.m.	Filtered P.p.m.	Settled P.p.m.	Filtered P.p.m.
0	500	—	135	500	—	135	—	135
24	425	168	98	425	215	130	184	105
48	420	138	63	480	195	130	150	93
72	310	65	47	400	198	—	—	—

Sewage was placed in six battery jars of equal diameter to two different depths (1.0 and 7.5 inches) and allowed to stand for 24, 48 and 72 hours. At each period a set of jars was used for the B.O.D. determinations and discarded. The jars were shaken and B.O.D. determinations made on portions of the sample including the settleable solids. Another portion was Seitz filtered and B.O.D. determinations made on the filtrate. The results are given in Table IV. In the jars filled with

TABLE IV.—*B.O.D. Values of Sewage Stored Under Quiescent Conditions in Deep and Shallow Layers*

Time Hrs.	7½ in. Deep		1 in. Deep	
	Not Settled P.p.m.	Filtered P.p.m.	Not Settled P.p.m.	Filtered P.p.m.
0	250	103	250	103
24	160	85	140	45
48	110	35	55	17
72	130	32	64	12

sewage to a depth of 7.5 inches the B.O.D. reduction after 72 hours was 120 p.p.m., in the 1 inch deep layer it was 186 p.p.m. after an equal period of storage. The Seitz filtered samples in the deep and shallow layers gave reductions of 71 and 91 p.p.m., respectively.

Discussion

The results show that significant B.O.D. reductions are obtained by keeping sewage under quiescent conditions in the laboratory The gross reduction in B.O.D. is the result of several agencies: (1) sedimentation, (2) bioflocculation and (3) stabilization. Significant reductions in the B.O.D. of the non-settled sewage show the rôle played by biochemical stabilization. That bioflocculation is also a factor is evidenced by the reduction in B.O.D. of the supernatant liquor on prolonged storage which reduction is higher than can be accounted for by stabilization and sedimentation. The reductions that occur on prolonged storage take place faster in open than in closed vessels; faster in shallow than in deeper layers. It can safely be assumed that conditions in the closed jars were completely anaerobic. In open jars partially aerobic conditions might have prevailed although no actual dissolved oxygen determinations were made. Sewage in shallower layers could maintain more positive D.O. residuals than in deeper layers. The evidence therefore points to the fact that both biochemical stabilization and bioflocculation are beneficially influenced by aerobic conditions.

The surface exposed per unit volume of liquid is greater under laboratory conditions due to the small volumes handled than in impounding reservoirs. This factor by itself would tend to make the laboratory results higher than those in impounding reservoirs. The greater surface exposed per unit volume would increase the surface reaeration and maintain aerobic conditions. However, since due to high dilutions aerobic conditions are usually maintained in the impounding reservoir receiving sewage the advantage in favor of laboratory scale experiments would probably be practically cancelled. Ridenour [2] reported that in an impounding reservoir (with an average theoretical detention period of 2.8 days) into which the effluent from a secondary type of sewage treatment plant was discharged, B.O.D. reductions in the summer season amounted to 66.5 per cent. Our laboratory results gave 80 to 85 per cent B.O.D. reduction in three days on sewage from which settleable solids had been removed.

Summary

Under laboratory conditions storage of sewage for three to four days removed about 90 per cent of the B.O.D. Part of this reduction was due to the removal of settleable solids, part to biochemical oxidation and reduction and part to bioflocculation. Excluding the settling of coarse solids, bioflocculation and oxidation-reduction gave 80 to 85 per cent removal of B.O.D. The removals were higher in open jars than in closed bottles and higher in shallow layers than in deep layers.

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Plant Operation

SEWAGE FLOWS AND COMPOSITION AFFECTING TREATMENT *

By A. M. Rawn

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Were one to consider the title of this paper in all of its implications he could not fail but conclude that its complete analysis and description would involve all of those factors which go to make up the practice of sewage treatment and the design of sewage treatment plants as they are known today. The writer will spare you such an ordeal however, having extracted from those implied two or three which seem to him critical, and to which he will try to confine his attention, feeling that the sin of omission rather than commission will increase the interest in the paper.

When wide extremes in flow and composition can be and are anticipated in advance of design and construction, a sewage treatment plant may be so conceived as to include methods and means of avoiding most of the operation headaches that accompany a greatly overtaxed disposal works. The art and science of sewage treatment has advanced, in the past twenty years, to where at least a good strong stab has been made at the reduction of wastes from all types of industries, mostly with pretty good success Good enough, at least, to let the designer know, with respect to a given industrial by-product, whether or not he can reduce it to innocuous form, about what can be done with it in combination with other sewage, or whether he can get along with it at all. Methods for the treatment of ordinary domestic sewage have been pretty well standardized. With this knowledge he is enabled to design a plant in such a manner as to reduce its chances of mortality to a very satisfactory minimum, provided, of course, the operator exercises a fair degree of intelligence in the conduct of plant affairs.

If the conditions of flow are not pretty well anticipated in advance, or even if they are, and then some industry of relatively great magnitude comes into the picture, the plant capacity may be so overtaxed as to result in the production of an effluent totally unsatisfactory for the type of disposal contemplated. This latter situation usually occurs in areas where the flow, which may come from any one or a group of industries, cuts a pretty high figure in the total for the plant.

Reduced to fundamentals, one discovers that he can get solids out of sewage by settling, floating or filtering them out. What goes on to get

* Presented at the First Annual Convention of the Sewage Works Federation, Chicago, Illinois, Oct. 3, 1940.

the said solids into shape for any or all of these three operations is now and has been for years the work of many earnest and persevering men who have met with varying degrees of success in their endeavors. The results of their work and efforts are written in thousands of words, hundreds of journals and dozens of books, and the best of the processes are currently used in the majority of treatment works. Furthermore, out of these efforts there emerge a few ideas which have been developed into tools to be used in balancing the equation between existing plant facilities and what might otherwise be severe overloads.

The plant designer is usually more or less optimistic about the attractiveness of the area to be served and generally allows that some years hence there will be more people and/or industries there than now. This optimism, plus a measure of knowledge regarding per capita and industrial flows, has usually contrived to render the plant quite capable of doing an excellent job through the years immediately following construction. That it continues to carry on in a satisfactory fashion after reaching what is apparently its design capacity and even going further to take on additional intermittent overloads without serious impairment of the effluent, is due largely to the nature of the sedimentation phenomenon; secondarily, to the elasticity of most oxidizing processes.

Examination of plant records discloses that extreme variation in the suspended solids load in an influent to a plain subsidence tank are reflected only mildly in the effluent. Still less, of course, where sewage is especially prepared for subsidence by flocculation. B.O.D.'s, only moderately affected by subsidence, are nevertheless reduced more than the variation in flow and load of raw sewage would appear to permit. Data indicate that as a rule sewage containing 400 p.p.m. of suspended solids will lose as many pounds of solids in thirty minutes in a well designed sedimentation tank as sewage containing 100 p.p.m. will in two and one-half hours. Stated in another fashion, sewage containing 400 p.p.m. of suspended solids will drop over half thereof in an hour, while that containing 100 p.p.m. will drop only one-fourth in the same length of time. It is also a fact that velocities in sedimentation tanks, and consequently through-put quantities, may vary widely from those calculated to be the optimum and still permit the process to yield excellent removals. By virtue of this, such treatment as follows primary sedimentation does not have to absorb the shocks of wide changes in quality, being cushioned therefrom by the primary sedimentation process. There is, fortunately, a definite elasticity in the oxidizing capacity of activated sludge and in sprinkling filters, which accounts for their ability to absorb short overloads without serious impairment of the final effluent.

The Richmond-Sunset sedimentation plant, built in Golden Gate Park, San Francisco, affords an excellent western example of the efficiency of subsidence. The average daily flow at this plant is at present about 7½ million gallons, varying between 2 and 11½ million gallons. When flowing at a rate of 2 million gallons the sewage contains about

110 p.p.m. of suspended solids, *i.e.*, 75 pounds in the one hour lowest flow. Flowing at a peak rate of 11½ million gallons, the sewage contains 400 p.p.m. suspended solids, or 1900 pounds in one hour's flow. During periods when the flow approximates the average, the sewage contains about 865 pounds of solids for a one hour period. Now it might be expected that these wide variations in influent would be reflected sharply in the condition of the effluent. Such, however, is not the case. The effluent suspended solids load varies between narrow limits of 40 pounds per hour at the peak, 30 pounds average, and 20 pounds at low; thus while the input varies from 75 to 1900 pounds per hour, the outgo changes only from 20 to 40. B.O.D.'s are reduced about 50 per cent under all conditions of flow, a remarkable fact when it is realized that pounds of oxygen demand varies in the ratio of one to seven from low to high flow. This plant affords an excellent demonstration of the ability of subsidence tanks to level off the condition of the effluent despite wide variations in the raw.

In evaluating conditions in an activated sludge or other oxidizing process calculations made at the plant outlet may, at times, yield a different picture than those at the inlet. For instance, if the same Richmond-Sunset *plain sedimentation* plant, which has such a wide variation in flow and composition, were assumed to be preliminary treatment in an activated sludge plant, *i.e.*, followed by aeration and final clarification tanks, one might conclude upon hasty examination that at the high rate of flow sewage would tear through the works with just a lick and a promise. Careful analysis would indicate, however, that much, if not all, of the sewage leaving the plant during periods of high flow would enter it during periods of low flow and have been there a long time. Further, that much of the sewage entering the plant at high flow would be pushed out by moderate or low flow, so that it also would stay much of the designed time. A plant's displacement capacity has an important bearing upon its ability to cushion against abrupt changes in its effluent and is a factor to be reckoned with in selecting a place from which to start an analysis.

The ability of a plant to absorb quick, short jolts or shocks is entirely different from its ability to continue to operate effectively under continuous overload. Shocks of short duration may test the elasticity of the plant facilities and the plant come out winner, but if the capacity is stretched and kept that way long enough, the process loses its resiliency, does not have a chance to recover during times of normal or less than designed load, and the effluent starts to reflect the condition by suffering degradation.

When the overload becomes continuous, the ability of the plant to take care of it may be greatly increased by assisting the subsidence process. One way to accomplish this is by flocculating the incoming raw sewage prior to sedimentation with or without chemicals. Such flocculation has not only a profound effect upon the removal of suspended solids in the primary tank but to a lesser degree the B.O.D. So effective is flocculation in improving the condition of effluent from

subsidence basins that this feature, installed at comparatively small expense in existing works, may be a valuable tool to be used in equalizing load to capacity. It also is being widely incorporated in the construction of new plants. It would seem unwise to use it in an effort to reduce the size of new tanks, which, because of their great value should not be scrimped in any event, rather, in new construction it is deemed advisable to include flocculation to increase the efficiency of sedimentation tanks designed along conservative lines.

The use of filtration through sand or iron grains as a step between primary subsidence and oxidation does not at present appear to be warranted in improving plant facilities. However, as a means of polishing off the effluent from a subsidence works prior to final disposal thereof it serves a valuable purpose and may be used to increase the efficiency of existing works otherwise incapable of doing the job alone. The sedimentation-filtration plant at Denver, Colorado, is an excellent example of this type of construction. There the effluent, first aerated and flocculated, is run through primary subsidence and during seasons of high flow or when irrigation is not being practiced down stream, discharged into the South Platte River. During periods of low river flow, and while the waters of the South Platte are being diverted for irrigation, the effluent from primary subsidence is run through magnetite filters, chlorinated and then discharged into the river. The magnetite filters are successful in increasing the percentage reduction in suspended solids from 71 to 77, resulting in a fairly clear effluent of good appearance. B.O.D.'s are reduced moderately by magnetite filtration but chlorination of the final effluent renders the river capable of completing the job without nuisance or menace to health to down-stream users.

The use of chlorine as a disinfectant applied to the effluent from primary subsidence, and also for the purpose of killing off attenuated organisms in the activated sludge itself, has in some instances resulted in an improvement to the plant effluent, and in that sense has, without additional construction, extended the plant's facilities to cover overloads. The application of chlorine and air to the incoming raw sewage or to the effluent from primary subsidence is said to materially increase the removal of grease when compared with ordinary methods of subsidence and flotation or aeration alone. There is some doubt whether or not benefit will accrue to the effluent from an oxidizing process by the removal of grease from domestic sewage to an amount less than that achieved by ordinary subsidence and flotation—however, additional grease removal from some types of industrial flow should be effective in reducing the load upon the more refined treatment processes and in this sense the aeration-chlorination process may be deemed a useful tool in expanding existing plant facilities. There is certainly no doubt but that the removal of as much grease as possible improves the effluent from ordinary sedimentation. Wherever grease has become a serious problem in the effluent its removal may be seemingly facilitated and improved by the comparatively simple procedure of

blowing air and chlorine through the raw sewage for a short time before the latter enters the subsidence and flotation chambers.

It is difficult to conceive of a situation where the capacity of an activated sludge plant was increased fourfold by the simple expedient of line chlorination—nevertheless such was the case at the Joint Disposal Plant of the Los Angeles County Sanitation Districts some ten years ago. During the early years of operation of the districts system sewage delivered through the warm slow flowing sewers was black and septic with the solids finely comminuted. It was high in dissolved sulfides and low in good sedimentation qualities. Despite the fact that the quantity of sewage flowing into the plant did not exceed that for which the latter was designed, the process was incapable of producing anything resembling a good effluent. By by-passing a portion of the load and increasing the quantity by-passed until the plant was capable of handling the remainder, it became apparent that the condition of the incoming raw was such as to reduce the plant capacity to one-fourth of that for which it was designed. Fortunately there was a means of correction at hand, in this instance, chlorination of the sewage at strategic points throughout the system and its maintenance in a fresh state while flowing to the plant. By this means the design capacity of the plant was restored at reasonable cost and without plant expansion. The instance is recorded as illustrating the profound effect which stale sewage may have upon otherwise adequate plant facilities.

There are situations in which flows vary so greatly between seasons as to indicate a plant of much greater capacity at certain times than at others. Two notable examples of this come to mind—one at Sacramento, the other at North Yakima. Sacramento, with a population of 100,000, at present treats the sewage by coarse bar screening with disposal of screened effluent to the Sacramento River. Recent studies, prompted by serious pollution of the river, indicate that in the not distant future more adequate sewage treatment will be necessary as the intermediate step between collection and final disposal. Factors which will lead to the design of a sewage treatment plant for this city indicate that tributary vegetable and fruit canneries contribute a population equivalent approximating 300,000 at the peak canning season, a condition which results from the overlapping of tomato and peach canning. This condition will last only for about twelve days in early September, before and after which the cannery population equivalent will vary from 60,000 to 150,000, depending upon the current pack. For five months in the year the plant will treat domestic sewage from 100,000 population. Careful study of this situation will, of course, permit the designer to plan for it but it appears obvious that in a plant where the load may vary from 100,000 to 400,000 population equivalent each year, the treatment works must be able to satisfy the greater load, remaining, in part, idle for much of the year.

Yakima, with a population of 22,000, operates a sedimentation plant treating an average daily flow varying from 4.9 million gallons in January, to 18 million gallons in August. The reason for the increase is

two-fold, first, rising ground water during the irrigation season; second, cannery wastes. At Yakima the plant is designed to treat the domestic load, plus a cannery population equivalent of 60,000 plus a quantity of ground water equal to three times the ordinary domestic flow. Obviously much of the plant is idle for many months of the year.

Cannery wastes, which are more or less a bug-bear in plant design in western United States, are responsible for many difficulties in sludge digestion. Palo Alto, which placed its plant in operation in 1934, is a case in point. The operator of this sedimentation plant states that by the end of 1935 a scum of tomato skins (which incidentally seem to resist digestion about as effectively as anything which comes down a sewer) had formed a scum mat four feet in depth which, by the end of October, 1937, had increased to eight feet in depth. In April and May of 1938, following the spinach canning season, the mat was twelve feet thick. The available remedy for the situation was to pump the scum out to a nearby field, which was effective in reducing it to a four-foot thickness. The top four feet of scum was by this time so tough that it couldn't be pumped. During the 1939 canning season the scum level increased in thickness again to twelve feet. For an excellent and humorous account of this "operation headache" which six years has not cured, read Mr. May's article appearing in *California Sewage Works Association Journal,* Vol. 12, No. 2. The point here is that the character of industrial waste at Palo Alto is such as to completely upset the normal functioning of a separate sludge digestion plant which would otherwise be ample and suitable for the purpose intended.

In a paper presented at the California Sewage Works Association meeting held September 16, 1940, at San Diego, Mr. May, collaborating with Mr. Kimball, states in part regarding the Palo Alto plant that during this year's fruit and vegetable canning season, garbage from the canneries has formed a scum 4 feet in thickness on top of the primary clarifier; that the remedy for this upside down subsidence seems to be chlorination of domestic sewage prior to its combination with industrial waste in order to hold the former in a fresh condition, prevent gas forming in the combination with subsequent flotation of the vegetable and fruit skins, etc. This is an added illustration of the damage which may be done by septic sewage in an otherwise adequate plant.

So on and on one might cite examples of plant disturbances resulting from changes in quantity and composition of flow. Enough of the unusual is present in sewage treatment to make it appear that inconsistency is the only consistent virtue of this thing with which we are dealing. Each has had his experiences, and their telling and analysis has let us develop something of a pattern into which all but the most unusual will partially or wholly fit. What to do in time of plant trouble is a question to be answered by each according to his facilities and capabilities, however, it is well to remember that cracking down on the incoming raw in the roughing process will protect the more refined treatment which follows from severe destructive shocks, that the cracking down process may be greatly assisted in a given plant at compara-

tively small cost by grease removal, flocculation and holding the sewage fresh. A final effluent may be brightened by filtration and rendered far less dangerous by sterilization. There appears no general panacea for continuous excessive velocities in aeration or final subsidence processes other than simply to build more plant.

Much depends upon the plant operator—so much in fact that one is seldom found who has not been called upon at some time to iron out inconsistencies in design. Try as the designer will, he cannot anticipate all of the vagaries of sewage—the plant operator must take up the slack. The more one sees of plant operators the more he is impressed by the fact that here is a man who is being molded into something of a common pattern. He is quite frequently one of the few citizens in the area to be served who has little, if anything, to say about the plant design. He is usually not in any sense responsible for plant capacity, equipment or proposed plan of operation. In a word, he is usually handed the plant with the inlet gate open and told to do his stuff well and ably for a comparatively modest honorarium. That he develops into a man of quick, and sometimes correct decisions, few words and a lurking disregard for the fundamentals of sanitary engineering, seems to follow because there are few circumstances which can inspire a man to precipitate action faster than a sewer full of sewage and an overloaded plant. Usually the few words which he utters at such time are unprintable and it isn't strange that he sometimes doubts the value of an engineering education.

MECHANICAL EQUIPMENT IN SEWAGE TREATMENT *

By L. M. Johnson

Engineer of Maintenance and Operation, The Sanitary District of Chicago

The use of mechanical and labor saving equipment in sewage treatment has had wide development in the past ten years. A large modern sewage treatment plant is primarily an assemblage of equipment for the mechanical handling of liquids and solids with necessary appurtenances and automatic controls. In a large plant, such as the newly constructed Southwest Sewage Treatment Works of The Sanitary District of Chicago, mechanical equipment must be operated and maintained from the time of arrival of the sewage at the works to the ultimate discharge of the effluent and the disposal of sludge.

The complex mechanisms of steam and power generation, the use of steam turbines for the main drives, the filtration and drying of sludge, the use of sludge as a fuel or fertilizer material, and the co-ordination of the many functions of the plant present problems that may prove to be either a mechanical engineer's paradise or a nightmare.

Even with an excellently designed plant it is essential that the mechanical equipment installed be properly operated and maintained by trained and competent engineers with a thorough understanding as to how the various units of equipment must function.

In The Sanitary District of Chicago, the design, construction, operation and maintenance of the sewage treatment works are accomplished by employees of the District. This unified engineering control has inherent advantages over a system where design, construction and operation are brought about by separate and distinct organizations. In The Sanitary District, design and operating organizations work together to foster development of improved equipment and devices which give promise of improving the art of sewage treatment, either by obtaining better results or by decreasing costs. Thousands of dollars have been spent by the District to reduce costs and improve methods, a portion of which has, in many cases, only shown what not to do. Failures of equipment reach the attention of the manufacturer, regardless of his responsibility, and suggestions for improvement are made, which are almost always gratefully received by the manufacturers.

Because of the legal limitations placed on municipalities it is, in most cases, incumbent upon the municipality to purchase equipment on bids from the lowest responsible bidder. This puts an additional responsibility on the designing engineer to word his specifications to cover many minute details which would be unnecessary if the equipment could be purchased outright. Co-operation with the engineers of the manufacturers must, therefore, be sought in order to prepare design and

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specifications that can be met and will produce equipment having the desired characteristics.

In The Sanitary District of Chicago, new projects have been handled in the following way: The basic problem is presented to the various division heads by the chief engineer. The division heads, including sanitary, chemical, mechanical, electrical and maintenance and operation, analyze the basic problem and determine the type of treatment and sludge disposal best suited. Studies are made of operating results of plants throughout the country, equipment manufacturers and operating and maintenance staffs are consulted to determine sources of troubles in equipment at existing plants and the corrective measures that have been taken to eliminate the difficulties. Conferences are held periodically between the various divisions, and all employees, from floor operators up, are permitted to bring suggestions to the front for consideration.

All of this thorough consideration of design, and particularly mechanical design, results in some increase of design costs, but in the case of the District this cost has been well worth while and will continue to pay huge dividends in operation. Unfortunately, not all communities look at the design cost as one which, if properly made, can pay for itself many times over. This thought is presented in opposition to the trend now so prevalent to reduce or limit the design costs of a project. Skimping initial costs only leads to reduced value for the dollar spent in construction and the spending of unnecessary funds at a later time frequently brought about by the inability of the designing engineer to give more time than that for which he is retained.

Maintenance of Screens.—Some of the mechanical problems with which the District has been confronted may well be discussed by taking the units of a plant in order. The first step to be considered is sewage screening. In The Sanitary District the function of sewage screens is merely to provide the necessary protection to the mechanical equipment following them. Screens are installed in the District varying in size from ½ inch to 10 inches clear opening, the former used to remove various materials from sludge which might cause trouble in the filtration process, and the latter to prevent damage to some of the larger storm-water pumping installations. The provision of mechanical cleaning devices follows the fixed rule that where costs of manual removal exceed costs of installing mechanical cleaning, the warranted mechanical devices are installed. In Chicago, where highly paid organized labor must be used, mechanical devices usually pay their way. To illustrate this situation, only hand cleaned screens are used to protect the main sewage pumps at the North Side Works where a relatively small percentage of storm water is handled, while the screens at the North Branch Pumping Station which have the same bar spacing as the North Side screens (4 in.) are provided with mechanical cleaning equipment. The North Branch Station flow varies over the wide range of from 75 to 1500 cubic feet per second. Mechanical cleaners are essential to as-

sure that the screens will be kept clean during high flows, thus preventing the screens from being clogged and becoming a dam.

In placing the new Racine Avenue Pumping Station in operation unexpected conditions were encountered. Due to excessive screening loads it was necessary to increase the openings to nearly 10 inches to permit proper operation of the cleaning mechanism. Fortunately, the pumps installed following the screens can pass solids as large as 10 inches diameter.

These installations illustrate the use of screens in the protection of sewage pumps. The other extreme of bar spacing is illustrated at the

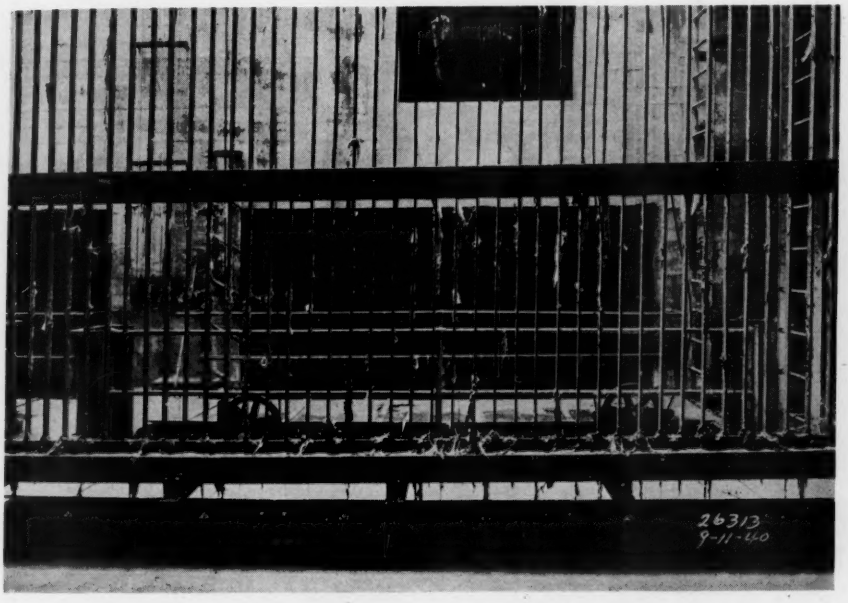

FIG. 1.—Tandem lift screens for protection of main sewage pumps, West Side Works. Identical units provided at the North Side Works, 4 in. clear openings. In background may be seen the other screen in lowered position.

Southwest Works, where ½ inch screens are used to protect the sludge pumps, pipe lines and vacuum filters. This bar spacing is necessary for the adequate protection of the equipment.

Concerning sewage screen cleaners, it can be said that no device has yet been developed which gives assurances of uninterrupted operation, due to the great variety of materials which are admitted into sewers. Because of the fact that any cleaner must employ some wiping or rubbing action to accomplish the desired results properly, excessive wear takes place with inherently high maintenance costs.

A development made in the Sanitary District has aided in the repair and replacement of screen units. This was a provision for hoisting the entire unit out of the sewage flow, the unit pivoting about the

head shaft. This feature has been incorporated in later screen installations and in some cases is quite desirable, in that an unobstructed channel may be had in cases of emergency.

From experience with screens a few general statements can be made. First—do not have the openings any smaller than are necessary to protect the equipment which follows: Second—screen cleaners may become inoperative by being fouled, and therefore all screens should be designed to withstand the full head to which they might be submitted if they become, in effect, a dam: Third—all the working parts of the cleaning mechanism should be able to withstand, without failure, the full

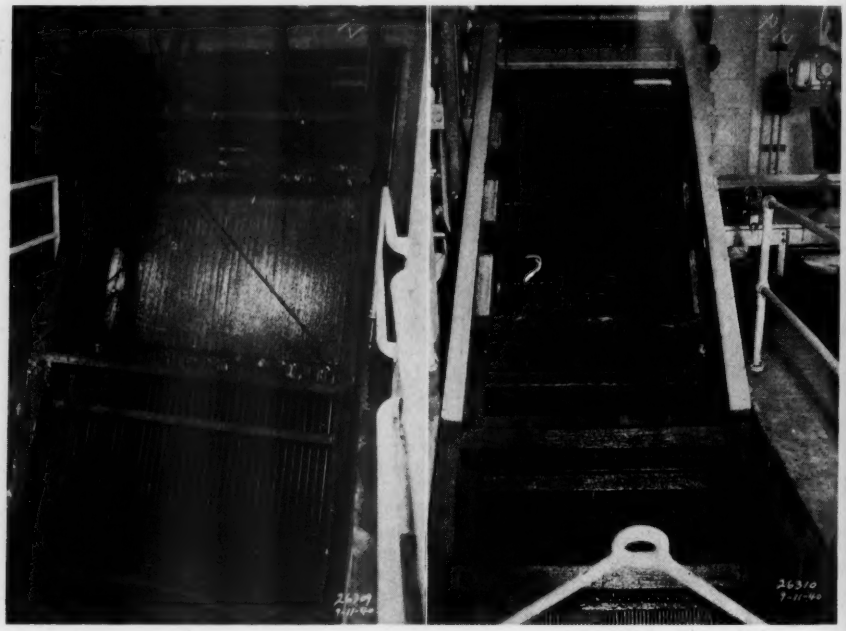

FIG. 2.—Southwest Works. Left—2 in. screens ahead of main sewage pumps. No screens are provided following the pumps. Right—½ in. sludge screen. Note bails for hoisting unit out of channel.

stress which can be applied to it. These precautions reduce failure and insure longer operating life.

The problem of screening is followed closely by that of screenings disposal. In most cases screenings, if permitted to stand, can become excessively offensive. Of late, a common and satisfactory method of disposal has been the grinding of the screenings, returning them to the flow and disposing of them along with the accepted methods of sludge disposal. The grinding of screenings is not, however, a cheap operation if they are ground fine enough to cause no trouble from balling or clogging in the succeeding treatment steps. Many satisfactory installations are in operation, however, and The Sanitary District employs

this method at the North Side and Calumet Treatment Works. Particular care is taken to do the grinding on off-peak power demand periods. At the new Southwest Works screenings are now disposed of by transporting them to the West Side Imhoff sludge dump. This method can not be considered desirable, as they become offensive, and they are difficult to load and unload in freezing weather. Consideration is being given to the incineration of the screenings either in the installed or

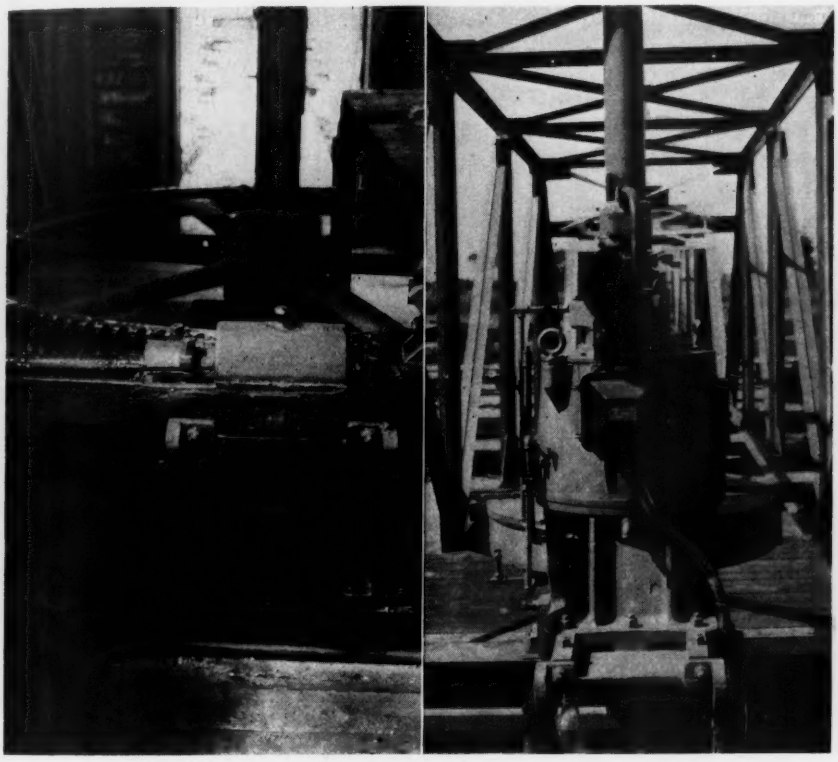

FIG. 3.—Final settling tank drives, North Side Sewage Treatment Works. Left—Old worm type gear drive. Right—Compact replacement unit.

specially built furnaces. In any event the costs will be high when consideration is given to the small amount of putrescible material to be handled.

Settling Tanks.—In preliminary, final, and concentration tanks where mechanical sludge removal equipment is provided, the mechanical problems are mainly those of wear, due to the dragging action of the scraping mechanisms, and the proper design of the drive for the mechanisms. The District has had severe trouble at the earlier plants from these two sources and great improvements have been made to correct these faults.

Concerning the driving equipment a common practice was to use the cheaper types of gear reduction units, with great sacrifices of efficiency, accompanied by excessive wear. Worm type gears are no longer used and extreme care is exercised to obtain well-cut gears constructed of proper material. Some original investment was also saved by the purchase of one central driving unit for several mechanisms, with necessary shafting, couplings, clutches and shear pins. Proper alignment was difficult to obtain in earlier installations and much trouble resulted from misalignment due to structural and temperature changes. This type of mechanism usually depended on a series of shear pins to protect the more expensive part of the drive and frequently the failure of

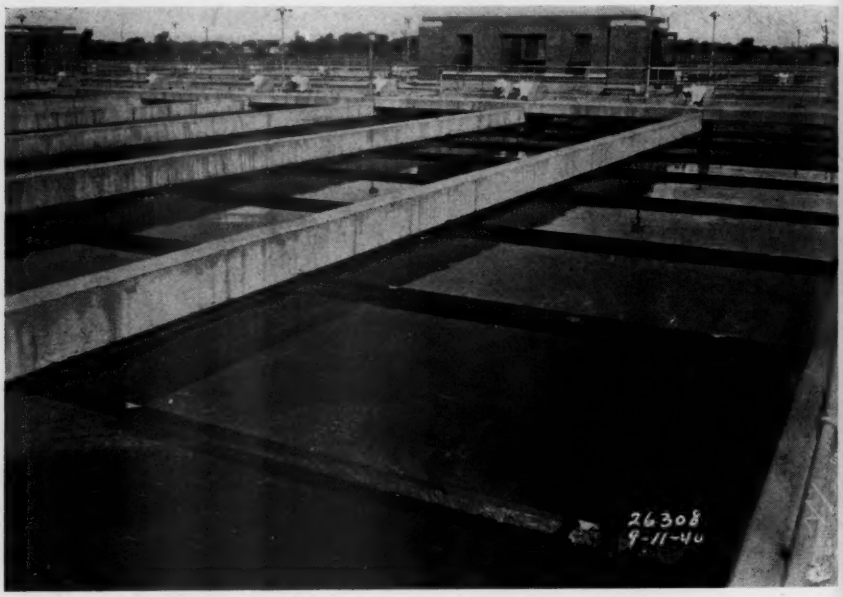

FIG. 4.—Southwest Works. Preliminary settling tanks. Note individual drives for each bay and removable wearing shoes on timber flights.

one shear pin would stop the operation of several units. Use of a heavier pin often resulted in gear or motor failure. The use of individual drives on each mechanism has now been adopted similar to the proven individual drives in modern shops which have replaced the old fashioned line shafting. This practice has led to the use of reliable overload protection on motors and the important feature of having all parts of the mechanism designed to withstand the full motor torque.

Particularly in rectangular preliminary tanks, where the collecting mechanisms must drag along the bottom to cause the settled material to be removed, considerable wear on the drag or flights was encountered. Frequent expensive replacements were reduced substantially by the adoption of simple wearing strips or shoes (Fig. 4).

In the case of circular tanks, maintenance items have been reduced by supporting the driving mechanism on a center pier rather than from structural steelwork spanning the tank. This method also gives a much more pleasing appearance to the tank units. The development of weather proof drive units eliminates unsightly "doghouses" previously provided for protecting these mechanisms.

Pumps.—Pumps are the heart of the circulatory system of a sewage treatment works and may be the source of serious trouble. The trouble mainly arises from the character of the material handled, and the maintenance problem is largely one of choice of equipment and the most effective and economical method of making repairs. Since the service

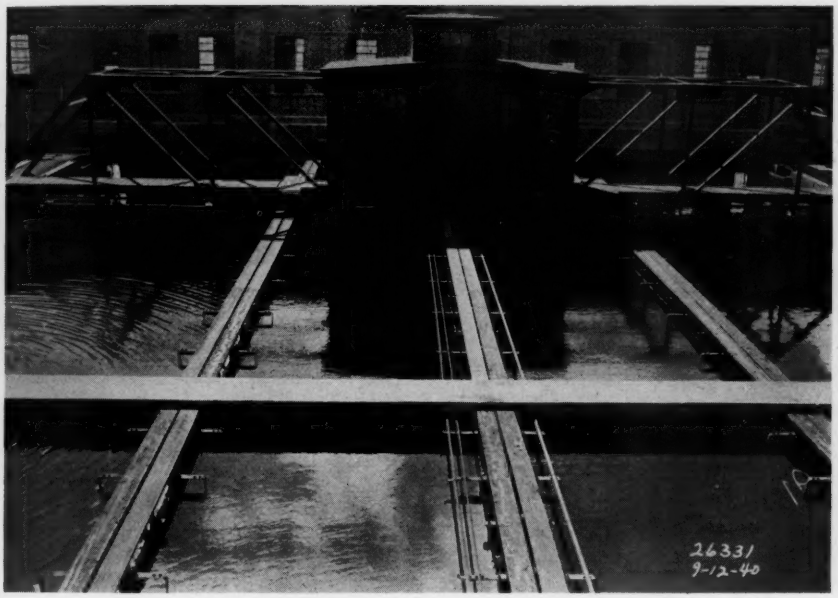

FIG. 5.—North Side Works. Old type final settling tanks.

varies with the type and concentration of the liquid, the degree of screening, the quantity and the head, it is difficult to lay down inflexible rules which cover every case. The following facts, however, have been proven in practice and merit consideration wherever economical maintenance and operation are desired:

Buying and selling of sewage pumps has usually been done on the basis of guarantees of high efficiency. Generally speaking, the high efficiency of such a pump, within reasonable limits, is a matter of small moment. The important requirement is the average efficiency over a period of years, and freedom from attention and repairs.

From the experience at The Sanitary District of Chicago it can be said that the most difficult pumping job is that of pumping preliminary

tank settlings or the settlings from a concentration tank including preliminary tank solids. Over the range of sizes in pumps used for this purpose, no pump is available to do the job without screening. The degree to which the screening must be carried depends, in a large measure, on the size of the pumping units required—the larger the pumps, the coarser the screen which may be used.

Pumps of ordinary design cannot withstand these severe operating conditions. On parts of the casing and impeller where excessive wear occurs, a hardened surface insures continuous service and justifies the expense. Pumps of these specifications are giving two year's service

FIG. 6.—North Side Works. New final settling tank.

before requiring a complete overhauling, only receiving occasional adjustment during the two-year period.

The pumping of the waste sludge from the North Side Works to the West Side Works, a distance of approximately 18 miles, through a 14 inch cast iron pipe line, introduced a pumping problem which, at the time, was unique in that there was practically no past experience by which to be guided. In view of this lack of precedent, the open impeller paper stock pumps originally installed were partially satisfactory. There was no difficulty from clogging. The cost of packing, renewing shafts, packing sleeves, bearings and side plates, however, was very high because of the frequent necessity of making these repairs.

The original pumps were replaced by specially designed pumps after seven years of operation, and maintenance work has thus been greatly diminished.

Wearing rings are a source of serious losses of efficiency and capacity of sewage pumps. Neglect of wearing rings can result in costs far higher than the cost of labor and material for their repair or renewal. It is desirable, therefore, to strike an economic balance whereby the maintenance of wearing rings is offset by the saving in power resulting from holding reasonably close clearances.

A considerable amount of experimenting has been done on Sanitary District sewage pumps in an attempt to find the material best suited for wearing rings. Cast iron has been tried for stationary and rotating rings. Bronze has been used for rotating rings in combination with a cast iron stationary ring. In general, the most satisfactory results

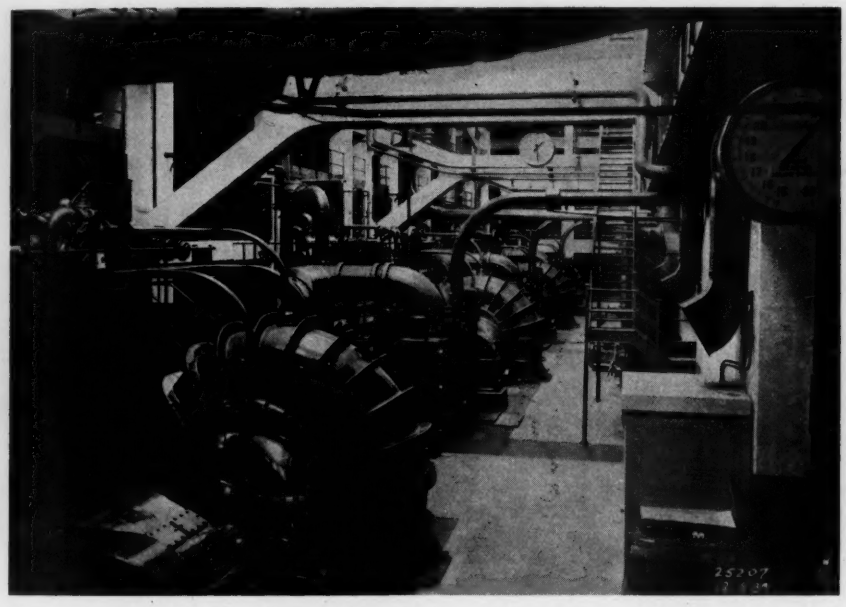

FIG. 7.—Southwest Works. Steam turbine driven main sewage pumps, 300 c.f.s. capacity each.

have been obtained by the use of a hard, abrasion-resistant material. A hard surface has been obtained by the use of the nitridation process, and rotating rings of this material have been used with a considerable degree of success in combination with a cast iron stationary ring. At the present time, however, the nitridation process is impracticable to perform on large size rings because no furnaces of adequate size are available.

All of the pumps at the North Side Sewage Treatment Works have now been equipped with wearing rings of cast iron, the wearing surface of which has been sprayed to a depth of approximately $\frac{1}{16}$ inch with a high chrome, high carbon steel which air hardens to a Brinell hardness of over 400. If care is used the surface can be sprayed sufficiently smooth to avoid the need for grinding.

The use of air lifts appears very attractive for certain uses. This device is used at the Southwest Works for handling return activated sludge and preliminary sludge. In general, air lifts are low in efficiency but the loss in efficiency through their use is partially offset by savings in replacement and maintenance charges. Flexibility and ease of control are hard to evaluate but must be considered. Where sufficiently large pipe sizes may be used the possibility of clogging is practically eliminated. The Sanitary District has applied the air lift only in rare cases for special services.

Aeration Equipment and Appurtenances.—Practically all large activated sludge plants use compressors of some kind for supplying air to

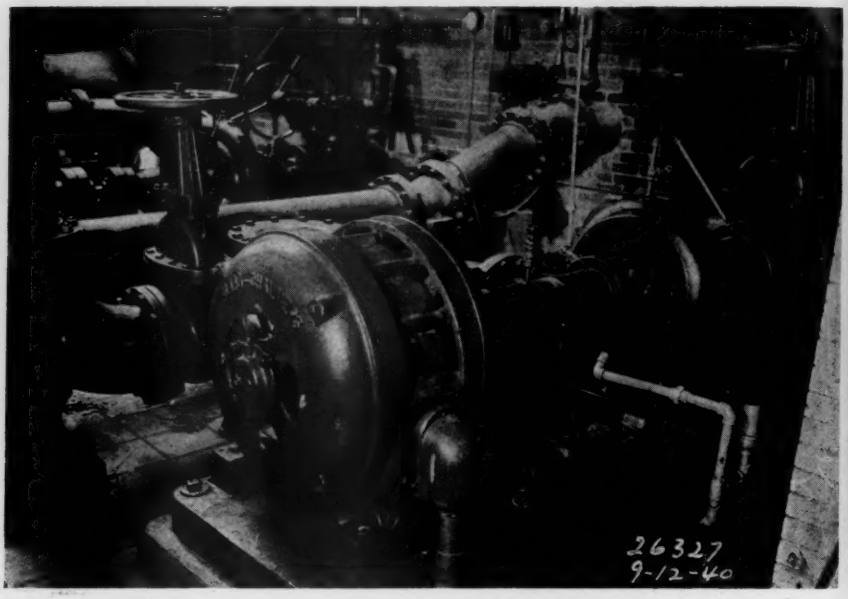

FIG. 8.—North Side Works. Waste sludge pumps. Operates under a head of 180 to 200 ft.

aeration tanks. Regarding blowers very little need be said other than that very little maintenance is required if a high class piece of equipment is provided. It should be emphasized, however, that the proper running balance must be secured and maintained. Also, the lubrication system must be inspected frequently to assure proper lubrication of high speed equipment of this kind.

Air filters are an important part of the blower system. Earlier installations have included sheet metal frame baskets filled with copper turnings mounted in a framework in the air stream ahead of the blowers. These must be removed periodically and cleaned, oil applied and replaced, or high head losses result. For later installations an improved cleaner has been available in which a multi-panel endless belt

is used. Each panel is made of a series of overlapping woven wire screens. The belt is mounted in a vertical position and passes through an oil bath at the lower end. The air passes through the belt twice, first on the rising side. Dust is deposited in the oil which is changed once or twice each year.

Diffuser plates are not a serious maintenance item except in unusual cases. The plates at our North Side Works have been in service for about 12 years and are still giving satisfactory service. At the Calumet Works a high proportion of iron wastes in the sewage caused clogging of the plates by the oxidation of ferrous hydroxide to the ferric state within the plate. Through cooperation with the steel industry the bulk

FIG. 9.—Southwest Works. Return sludge air lifts, showing 2 16-in. lifts for one settling tank.

of the troublesome wastes have been removed from the sewers and the trouble materially lessened.

Sludge Handling.—The sludge problem and the development of the accepted methods of handling sludge has given rise to a great deal of mechanical development. The development has been from small hand cleaned sludge drying beds, and plate and frame presses in some of the larger plants to the present day installations of vacuum filters, flash drying and incineration units, or filters and multiple hearth furnaces. Along with this has been the adoption of equipment for removing and handling sludge from drying beds, the development of digestion tank mechanisms, digester gas collection, and the utilization of gas in gas engines.

Most mechanical developments have been made, however, in plants

using filters and some method of drying and incineration. Briefly, equipment which has been developed or adapted for use in the sewage works field includes vacuum filters, ferric chloride storage, dosing and handling equipment, conveyors for wet cake and dried sludge, sludge mixers, dryers, heat exchangers, cyclone separators, and furnaces.

The use of vacuum filters has led to the selection of a suitable material for wire screen, filtering cloths and winding wire. The filtering medium is, however, the most important item of maintenance, because of the rather high cost of the material, and the labor required for changing. Cloths of all virgin wool twill weave, 12 oz. per square yard, have been found most satisfactory thus far in The Sanitary District. Work is being done at one of The Sanitary District plants on a one ft. by one ft. filter in an attempt to develop filter mediums of other materials. Replacement of the sludge scrapers on the filters by new ones of 18–8 chrome-nickle steel has been found desirable at the Calumet Works.

The general use of ferric chloride has required the use of rubber-lined pipe and tanks in the sewage works field. A new pump for handling ferric chloride has been found very satisfactory. The portion of the pump in contact with ferric chloride is made of rubber. Uniform hydraulic pressure is applied to the diaphragm, resulting in a minimum of flexing and maximum life. Other equipment developed includes apparatus for continuous pH records, and ferric chloride dosing equipment.

Conveying equipment finds extensive use in a sludge handling plant and many things have been learned regarding its use. Experience has indicated the necessity of eliminating the elevating of sludge cake beyond the ability of a belt conveyor. At the Southwest Works the layout is such that the sludge need be elevated only in its liquid or dried state. Belt conveyors are very satisfactory for handling wet cake if care is taken to insure clean pulleys at all times.

Air transport lines for dried sludge present difficult abrasion problems, particularly at bends. Here renewable sections of high hardness castings or shaped plates which may be readily inserted have been used. Concrete made of lumnite cement has also been used with satisfactory results.

Another serious abrasion problem has been encountered in the cyclones of the sludge drying system. At the Calumet Works a gunite lining has been applied. This consisted of lumnite cement and crushed trap rock (ganister) reinforced with 3 in. by 3 in. No. 10 galvanized steel mesh. The original liner plates were ¼ inch steel. Replacement costs were $800 to $900 and the life of the plates was comparatively short. The gunite lining was also used in a stack where severe corrosion, caused by condensation of vapor, was encountered.

Another problem that had to be met was the abrasion of the bars in the flash dryers. The solution has been the use of renewable sleeves that can be replaced as they wear out. Sleeves of various steel alloys are being tried at the Calumet Works.

Sludge mixers, which stir proportions of wet cake and dried sludge to a mixture of 40 to 50 per cent moisture, are subjected to combined abrasive and corrosive forces. Here 18–8 stainless steel plates are used in the mixing trough. The paddle tips are made of a chromium-tungsten-cobalt steel alloy. This alloy has successfully eliminated undue wear of the tips.

At the Southwest Works many operating problems have been encountered in the operation of the furnaces and drying system, as the steam load and the drying load are subject to rather sudden variation. Complete automatic control equipment is essential and is provided. Nevertheless, problems of control do arise and must be met. The use

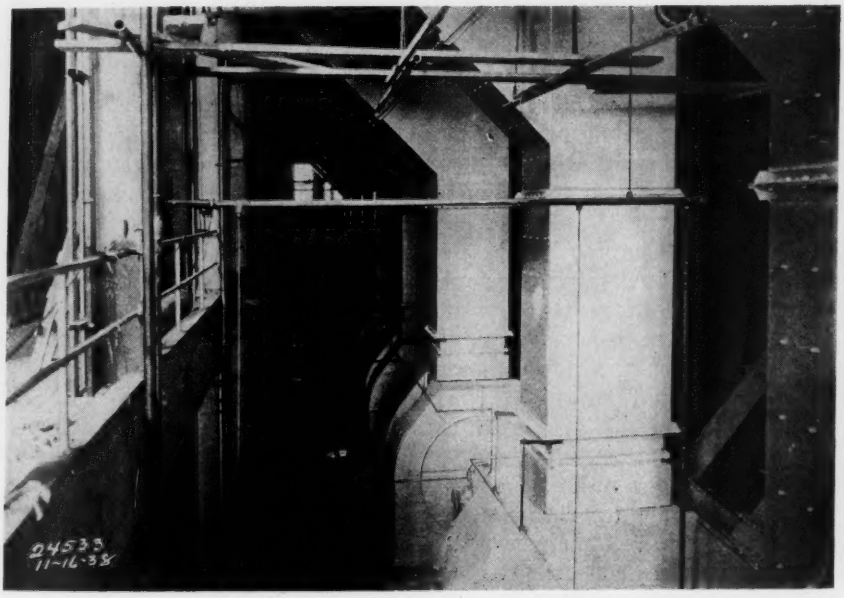

FIG. 10.—Southwest Works. Flash dryers.

of variable speed drives on the boiler induced draft fan is now being tried. Tests are also under way on various arrangements of the secondary air opening in the furnaces.

In this discussion only a brief outline has been given of mechanical development and of the adoption of mechanical devices in the field of sewage treatment. However, after seventeen years operating, maintaining and developing mechanical equipment in sewage treatment works, I feel I may safely predict that we will see even more complex and automatic mechanical equipment in future works. In view of the accepted necessity of improving stream conditions throughout the country, we, as engineers, should investigate thoroughly all mechanical equipment which gives promise to improve sewage treatment, or reduce costs, so that more and better sewage treatment works can be built.

DISCUSSION OF THE PAPER BY MR. L. M. JOHNSON *

By Charles Gilman Hyde

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This discussion of the subject "Mechanical Devices in Sewage Treatment" has been prepared as an independent contribution because, through the fortuity of time and distance, the author's paper has not been made available to me.

In "Modern Sewage Treatment," the Anniversary Book of this Federation, Chapter I, Introduction, "A Review of Progress in Sewage Treatment During the Past Fifty Years in the United States," I found occasion to say: "Since 1919, the trend is marked in the United States toward all sorts of mechanical equipment instead of manually operated devices, with the general result that plants are now far cleaner and more comfortably operable than in the past and are rapidly approaching the white uniform and kid glove stage of cleanliness. Moreover, present day equipment is being constructed with a view to greater ruggedness and longer service."

Pearse, in Chapter II, Functional Outline of Processes of Sewage Treatment, remarks: "In the forward development of the art of sewage treatment and the greater size of the plants, the use of mechanical devices has grown tremendously. In the large works today, mechanical and electrical engineers work in co-operation with the sanitary engineer on operation and design."

It is indisputably true, with respect to the larger sewage treatment works at least, that the advent of mechanical equipment has induced profound changes in both design and operation. Today neither can be the work of a single professional group.

Structures are, on the whole, more complicated. Equipment comprehends devices concerned not alone with the handling of sewage, grit, screenings, grease and sludge *per se*, but with electrical and gas power, and with dosing, controlling, indicating and measuring devices of every description. The electrical power may be produced at the plant by internal combustion engines, sometimes of large capacity. Air compressors and blowers are employed for grease removal, and in the activated sludge process. The simpler methods of sludge disposal of the past have given way in many instances to relatively complicated dewatering, drying and incinerating installations. Fertilizer is being produced and shipped to far-away destinations. Mechanical filters are being added to improve effluent quality. Plants of the sort in question require complicated switch boards and conduit systems to supply the demands for power, lighting and ventilation. Heating and plumbing are essential to the buildings as well as laboratory facilities. Thus the services of

* Presented at the First Annual Convention of the Sewage Works Federation, Chicago, Ill., Oct. 3, 1940.

the sanitary, the structural, the mechanical and the electrical engineer, together with those of the architect and landscape gardener, are demanded if successful design and construction are to be achieved.

In the operation of these larger works the services of trained electrical and mechanical engineers and attendants are required quite as much as are those of the sanitary engineer and chemist. This represents a very different situation from that which prevailed two decades ago. However, it must be noted that large plants such as are now fairly numerous were not then in existence.

The extent to which mechanical equipment should be utilized in the smaller plants is a matter which deserves careful consideration on the part of designing engineers. While it may be said with some truth that the very existence of such devices may foster better and more intelligent operation, the designer must at least face that hazard. It is obvious that the proper operation of complicated mechanical equipment and devices demands intelligent, skillful operation. Unless such is to be vouchsafed, simpler design is called for.

Due to the natural desire of designing engineers to reduce the physical burden of operation, and perhaps to the importunities of those whose job it is to sell equipment, there has been a tendency to install too much equipment in relatively small plants. This writer has seen sewage treatment works built to serve a few hundred persons in isolated country villages equipped with mechanisms which have never been made to operate and have lain idle with disastrous results as far as the quality of the effluents was concerned.

Although this may not be a popular matter to broach at this time, the writer is disposed to air two pet peeves which seem to bother him in respect to the general subject of equipment. One of these concerns the trade names with which some of these devices are being dubbed. The other relates to the character and lack of information in some trade catalogues, if indeed they are worthy of such a designation.

How for example, can any self-respecting, dignified engineer hope to live down the reputation of having installed in a plant for which he is responsible an "Aerotapivator," a "Bioflocigester," a "Biochemulator," a "Multrotdistrib," or even a "Spirovortjector"!

Too many effusions of the manufacturers of equipment—not alone, by any means, in the sewage works field—seem to be aimed at the schoolchild rather than at the of-age designer and purchaser. They are like copies of "Life" or "Look," with many beautiful pictures but a great dearth of the sort of information essential to design and installation. Data of specific performance are too seldom stated and an indication of costs almost never. Some literature which comes to our hand has complicated foldings, opened only at the expense of time and ingenuity, the which becomes as expansive and altogether unwieldy as are our own daily newspapers in crowded street cars.

Fortunately this castigation does not apply to all such publications. Many are replete with just the information which is sought: capacities,

sizes, speeds, space requirements, specific performance figures, etc. In some types of enterprises general ranges of prices are stated to the immense satisfaction of would-be purchasers.

As an example of trade literature in another field—that of water supply—the writer has failed to discover in any manufacturer's publication definite information concerning the loss of head, either with downward or upward flow, incident to various rates through various grades of zeolite. This is perhaps a rather typical illustration of the failure to supply information as essential to design as is the performance of the product itself.

Notwithstanding this tirade, the writer feels that as a rule manufacturers of sewage treatment equipment and accessory devices have been alert to supply those mechanisms which the designing engineer needs. These have been steadily improved in respect to performance, durability and appearance. Manufacturers are gradually getting away from the practice of attempting to make devices developed for use in other fields serve the exacting requirements of this one. In other words new devices are being developed for the specific needs of sewage and industrial wastes treatment. It remains for the engineer to acquaint himself thoroughly with what the market affords and to select that which is best adapted to his purpose at the least cost for installation and operation consistent with effective performance.

LICENSING OF SEWAGE PLANT OPERATORS *

By Charles C. Agar

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Licensing of sewage plant operators is not new for we have to go back over 20 years to find the first instance of a state establishing standards and reviewing the qualifications of sewage plant operators. New Jersey was the first state to start a licensing procedure, but it was fifteen years later before any other state took definite action to control the caliber of sewage plant operators. However, the past few years, particularly since 1935, have seen an accelerating adaptation of the principles of licensing for operators in both the water and sewage field. A great part of the recent impetus to licensing has been brought about by the operators themselves through their associations or conference groups and encouraged in most instances by State Health Departments or similar agencies. It is significant that the first state to have an association of operators (New Jersey) should also be the first to have a license scheme. The adoption of some form of licensing in other states has been preceded by the formation of operator groups or associations.

Since the formation of the Federation of Sewage Works Associations in 1928, we find that licensing has been a subject of increasing interest. The activity of operators' groups and associations is not the only factor in the progress made, for State Health Departments have long recognized the need for some workable plan to assure competent operators for sewage plants and reduce the frequent and recurrent turn-over with each new administration. However, the growth in licensing has been largely due to the efforts of operators. They have wanted it, and it is only natural that this would be a step following the organization of an operators' group or association. Here we have a group of operators attending conferences, short schools and meetings to meet their fellow operators, to take part in discussions, to study and improve their ability to do their work. But what of all this effort and activity if there is no recognition of their greater ability and accomplishment, if they may be replaced without question or redress or if the municipal authorities think of the position of operator as just another job that anyone can fill. There has come, therefore, the demand for recognition of ability as apart from other men in the community, the elevation of the position of operator to one having some professional status and an increasing security by tenure of office.

Tenure of office is apt to be the paramount factor in the mind of the operator. A man cannot do his best work if he must always be playing politics to hold his job and even then with uncertainty. There is rea-

* Presented at First Annual Convention of the Sewage Works Federation, Chicago, Illinois, Oct. 4, 1940.

sonable justification for this point of view and the licensing plan can do much to fulfill such an objective.

From the point of view of the State Health agency the main objective in licensing should be improvement in the operation and control of sewage treatment plants, thereby serving the best interests of the state and the community. Tenure of office becomes a secondary consideration but in many cases it is so closely allied with the main objective that it becomes a part of it.

Most states have had for many years laws regulating the design and construction of sewage treatment facilities and many states require the approval of plans for such installations by a state agency. One of the conditions of approval of such plans frequently is that the plant will be operated to the satisfaction of the State Department of Health. How can satisfactory operation best be secured or its continuity assured unless there is recognition on the part of the municipal authorities either by their own volition or by statutory requirement of the need for competent operating personnel to meet the plant requirements?

The term "license" implies that it is authoritative permission to do something, as to practice some trade or profession which cannot legally be done without such license, similar to the requirements of a form of license for a stationary engineer, a ship's captain, a doctor or a plumber where certain qualifications must be met before one is empowered to carry on his work. In granting a license it is presumed that the applicant has fulfilled all requirements as to education, training and experience established as a pre-requisite in the particular field for which the license is required. In this respect a license becomes a certificate of competency or official approval of the qualifications of the person to carry on a certain type of work.

Can municipal appointing authorities be relied upon or are they always able to select competent personnel to operate the sewage treatment plant? The answer is usually "No." Too often the appointment of the sewage plant operator has been made from the list of the political henchmen who are to be rewarded. Therefore, a standard for such personnel is needed and the license can serve as the necessary guide or aid to the appointing authorities. When licensing is under statutory regulation, the requirements must be met. Nevertheless, even with only a voluntary system of licensing in effect, municipal authorities cannot afford to disregard the standards established. Appointing officials having the best interests of the municipality at heart welcome the restrictions placed on the appointment of operators. In fact in many instances the existence of the state regulations in New York has served as a convenient excuse to retain experienced operating personnel at water and sewage plants when changes have taken place in the political complexion of the administration. The regulations have also served as an excuse to go outside the community to secure men to meet the requirements.

In general there are three main methods of appointment to a position of superintendent or operator. The first method is one in which

the appointment is made where there are no restrictions or regulations regarding the caliber of the man. There may be a purely political appointment with all its attendant disadvantages because of the usual lack of proper qualifications. More fortunate are those communities which rely on the advice of their consulting engineers and retain them for some time in supervising the operation of the plant.

A second method used in a few municipalities is one in which the appointments are made from lists of candidates established as a result of Civil Service examinations. As far as known there are no states where all municipal appointments are made under Civil Service regulations. The application of Civil Service is largely a matter left to the discretion of the municipality and the municipal authorities may request the establishment of a Civil Service list of qualified candidates. In a community where Civil Service requirements are in effect, there is a considerable advantage over the first method, but there needs must be close cooperation between the Civil Service Commission and the State Health agency to secure satisfactory results. Once having selected a competent operator, it becomes a responsibility of the health agency to see that a satisfactory standard of performance is maintained. In most cases the man originally adjudged competent by the results of a Civil Service examination continues to be an efficient employee but exceptions serve to question Civil Service as a "cure-all" for positions as sewage plant operator.

Civil Service is, therefore, considered to be a step in the right direction and its principal advantage is that it does tend to insure tenure of office. Once having passed the probationary period a man cannot be discharged without specific charges of incompetency, insubordination, etc., and opportunity for hearing must be given. The result may, therefore, be that Civil Service without some continuing incentive or requirements does not necessarily keep a man on his toes.

In New York State, although Civil Service is optional for a municipality, there are comparatively few instances where sewage plant operators have been placed under such plan at the present time. However, there is a trend in the State toward greater application of this means of securing qualified personnel at sewage plants. A recent ruling of the Appellate Division of the Supreme Court has in effect stated that all appointments of employees in municipal subdivisions in the State are illegal unless they have been made under the merit system referring to Civil Service. This ruling places a new and far-reaching interpretation on the application of Civil Service requirements in the State. Hearings are now being held by a committee of the legislature to determine the conditions under which Civil Service may be extended generally to all municipal employees.

The third method of appointment of a sewage plant operator is that in which the qualifications of the appointee must be approved by some state agency or he must have a license which qualifies him for the position. In a strict application of the true license scheme, appointments can only be made from a limited list of those already having licenses.

A modified form of procedure in which the qualifications of a prospective operator are submitted for approval before an appointment is made has merit in that a measure of "home rule" is retained. Even though so-called political expediency may enter into the appointment of sewage plant operators, the state should not use this as a principal argument for compulsory licensing and control of the hiring and firing of municipal employees. Centralization of authority is, of course, a trend of the times, but this writer feels that the principle of home rule with only sufficient restrain or guidance by the state to assure a reasonable measure or standard for an appointment is for the best interests of the municipality and the state.

A plant, in order to operate effectively, must not only have a competent operator, but also must be supplied with the wherewithal to accomplish satisfactory results. This means that an operator must be able to work with and secure from the municipal authorities what is needed. His relations, therefore, in order to be successful must be in harmony with the local administration. It is conceivable, therefore, that with the operator responsible primarily to the State under a statutory license plan, relations between the operator and the municipality might at times become strained, resulting in defeat of the principal object of the licensing; namely, betterment of plant operation. Therefore, it would seem that a licensing procedure in which the state exercises only a limited control is to be preferred. The limit of such control could reasonably be that a municipality may discharge any operator it desires, but his replacement can only be made with a man having the required qualifications, or a license for the grade of plant involved.

While much of the effectiveness of any license plan depends to a great extent upon its administration, a liberal interpretation and application of regulations will do much to foster harmonious functioning of the plan particularly during the first few years when it is in a sense on trial. It is only natural that there should be a gradual tightening up of the requirements as time goes on and the advantages of regulations become more generally recognized.

The general public is the party which should be the most interested in securing competent supervision and operation of sewage treatment plants. A good operator can get maximum results with sensible economy. The plant represents an investment of a considerable amount of public funds for a definite purpose; namely, to treat the sewage wastes of the respective communities so that they will not become a menace to water supplies, shell fish areas, bathing areas, etc., or create any public nuisances in the vicinity. As a good business proposition, a plant costing many thousands of dollars should be placed only in the hands of a thoroughly qualified operator if the investment is to be properly protected and intended benefits secured. But education of the public must go along with the licensing program if the public is to appreciate the advantages.

The advantages of licensing to the operators themselves are recog-

nized and borne out by the large number of states in which the initiative in promoting a system of licensing has been taken by operators' groups and associations. The establishment of standards and qualifications for sewage plant operators places such positions on a recognized plane of employment. Not every man can secure a license. The position is, therefore, one in which a man can take some pride in having qualified therefor. He obtains in a measure a professional rating. He is encouraged to improve his status and grade by application to his work and attendance at short schools and conferences. The respect of his superiors is increased and a better salary can be a logical result.

The case for licensing, with the many and varied reasons therefor, has been discussed but there are some disadvantages of the licensing system, many of which can be dismissed with little comment while others must be recognized.

From the Health Department point of view, there are no disadvantages which are considered of sufficient weight to offset the many advantages of a licensing plan. It is true that the administration of a license plan will require time and personnel with ability to analyze and review the qualifications of the candidates. Control of the qualifications of operators should actually reduce the work of training new operators and straightening out plants up-set through changes in operating personnel. A license plan, therefore, working effectively, should in time reduce the needed supervision of sewage treatment plants and make more time available for other activities. If the administration of the regulations regarding licensing is carried out impartially and without regard to politics, the plan should continue to be effective.

From the point of view of the operator, licensing may represent just another example of red tape and governmental regulation. Some inconvenience and possible expense are entailed in making out the application and subsequent renewals. Where examinations are required, older men with more experience but less school training are sometimes placed at a disadvantage. Furthermore, the possession of a license does not necessarily assure tenure of office.

There is also a limit to the scope of any examination for determining fitness for a particular job. The operator of a plant, particularly one in which other men are employed must not only know his job but must have administrative and executive ability as well. He must not only be able to carry out the work but also must be able to handle men. A satisfactory personality and ability to work harmoniously with the administration are necessary attributes of a good operator. Written examinations and in fact oral examinations as well cannot hope to determine fully a man's fitness to handle men or serve in an executive capacity. Such examinations also have limitations in determining an operator's ability to handle and care for mechanical and electrical equipment.

From the point of view of the general public, licensing imposes a restriction upon the freedom of action in the community. This may again be considered as state interference in domestic affairs and viola-

tion of the principle of home rule. There may also be the possibility, though remote, of the licensing board becoming a politically-minded group and this would defeat the intent of the licensing regulations.

Some comments on the operation of the New York State regulations will serve to point out a few of the problems which may arise. Legislation enabling the Public Health Council of New York State to prescribe the qualifications of sewage plant operators was enacted in 1937 and regulations consisting of Section F, Chapter XI of the State Sanitary Code were put into effect on October 1, 1937. According to the Public Health Law, the State Sanitary Code does not apply to New York City and, therefore, the regulations are not in effect in that city. All positions of operator in New York City are, however, under Civil Service. Furthermore, the regulations do not at the present time apply to operators employed by private institutions or companies. The law as passed relates only to those operators whose salaries are derived from public funds.

A "grandfather clause" restricts the application of the regulations to operators appointed after October 1, 1937 and, therefore, exempts operators employed before that date. This does not mean, however, that exempt operators are qualified but only that the necessity for securing approval of qualifications does not apply. Appointments of new operators cannot be made without complying with the Code provisions and the operator so appointed must have the requisite qualifications as defined for the particular grade required for each plant. Provision is also made for the issuance of temporary waivers for operators who do not fully meet the requirements at the time of appointment. For example, if an operator meets the physical, educational and other requirements but lacks some experience, the Public Health Council may grant an operator a temporary waiver (one year) until such experience has been obtained. Such a waiver is granted, however, only upon the request of the appointing authority and when substantiated by good and sufficient reasons therefor. Waivers can also be granted operators requiring completion of a short course in sewage treatment before becoming fully qualified. The New York State Law is patterned along the lines of the requirements for the approval of qualifications for health officers.

Qualifications are established for three grades of operators depending upon both the size of the community served and the type of plant to be operated. Operators subordinate to the chief operator are required to have at least qualifications of the grade next below that of the chief operator or superintendent.

The details of the regulations in effect in New York State will not be discussed as they have been described by A. F. Dappert in the paper presented before a Joint Meeting of the New York and New England Sewage Works Associations and appearing in the 1938 *Sewage Works Journal*, 10, No. 6, page 987.

Experience in the application of the regulations in New York State has for the most part been very satisfactory. As in the starting of any

new regulations a few unforeseen problems have arisen but none of these has been sufficient to seriously hamper the general effectiveness of the plan.

The position of operator of a sewage treatment plant is no longer the political football which it has too often been in the past. It is necessary to select the operator for a new plant with care and consideration of the qualifications prescribed. Changes in operating personnel at plants while not prevented, have been reduced greatly. The plan has served as a deterrent to indiscriminate hiring and firing when a new administration takes office. However, if a municipality deliberately sets out to circumvent the intent and purpose of the regulations there are occasionally means to "get around" the intended interpretation of the requirements. The use and abuse of the "grandfather clause" can serve as an example. It was not the intent of the regulations to exempt all previous operators of a plant regardless of the date or extent of previous service, or without taking into account changes in the size and type of plant made in the interim. However, a literal interpretation of regulations as originally adopted would exempt all previous operators regardless of their present qualifications for the position. In fact, as mentioned before, exemption does not in any way indicate approval of qualifications but the regulations have been interpreted so that the exemption was tantamount to approval. This possible condition has largely been eliminated by a change in the regulations so that the exemption only applies to operators actually employed and who have been continuously employed in the same position since October 1, 1937.

The regulations in New York State have been in effect now for over three years. During this period, approval of qualifications has been granted for 44 Grade I, 63 Grade II, and 200 Grade III operators, making a grand total of 307 approved operators in the state. In addition, there are a total of 65 operators now serving under waivers in one of the three classes, most of them being in Grade III.

In the case of any new regulations promulgated by a state agency and radically changing previous conditions, there must necessarily be a period of transition in the application and interpretation of the requirements. This is the period through which we have been passing in New York State. Once having been established, however, and recognized throughout the state there can logically come a gradual tightening up on the requirements. Whereas a liberal interpretation of the combination of education, training and experience required for a particular grade at the start was logical and reasonable, there can and should come a gradual raising of the standards for each applicant as the operators improve themselves and the value of higher standards of operation becomes more generally recognized by municipalities and the appointing officials. Thus we find that it is more difficult to secure the approval of the Public Health Council today, particularly for the higher grades of operator, than when the regulations were first adopted.

The regulations have had their greatest noticeable effect in raising the caliber of the men being selected as operators by appointing offi-

cials. The need for careful consideration of the requirements has generally resulted in the selection of candidates who more than meet the educational pre-requisites. For example the educational requirements for a Grade II operator include graduation from high school or its equivalent. Out of 63 operators approved in Grade II 34 or more than half have had college training. The great majority of them have completed their college courses and have received degrees. It is unknown of course what would have been the standard of educational attainment without regulations but a review of the prior education of exempt operators in Grade II plants shows that it is far lower on the average than that for recent appointments.

From the point of view of the operator the regulations have not always operated as anticipated by him in assuring tenure of office. It was commonly but erroneously considered that an approval of qualifications carried with it security in the position as operator. This is not, however, the case as a qualified or licensed operator can be replaced by another who meets the requirements of the particular grade of plant.

There are also some operators who have for a period of years been operating plants coming in the classification requiring for example a Grade II approval. They may have secured approval in Grade II but do not wish to be considered as "second rate" operators. So far as their particular plants are concerned, they may be doing a first class job but under the present code where they lack some of the requirements, it is not possible to approve them as Grade I operators without their completion of major courses and training. This condition also applied in a somewhat similar way to a few exempt operators who are operating some type of Grade I plant but cannot be given more than a Grade II approval for lack of some of the requirements for the Grade I classification. These conditions are receiving consideration and in time it is expected that a satisfactory solution will be found.

The greatest field for advancement of operators at the present time is from the Grade III to the Grade II classification. Special training courses of two weeks duration at three universities have been conducted for operators needing or desiring such training to fulfill one of the requirements for Grade II operators. An extension course consisting of four hours each week for a period of 30 weeks is now being conducted at another university to meet the requirements for Grade II.

While provision has been made in the regulations for special examinations for those desiring to advance in rating this provision has not been used to any extent to date. It is probable that this means will be adopted and applied more generally to determine fitness of candidates desiring to qualify and advance in grade.

In order to obtain a picture of the present status of the licensing of sewage plant operators in the country, a questionnaire was sent to each state sanitary engineer or director. Analysis of the summary of the information received confirms the conclusion that there is a definite trend toward some form of licensing in the country. There are a total of 15 states which have a licensing or certification plan either in opera-

tion or about to start this year. Some of these operate under a statutory requirement but most of them are on a voluntary basis. It will be noted that 11 such plans are or will be on a voluntary basis while only four are required or authorized by specific statute at the present time. In one case legislation has been passed, but the state has not been able to take advantage of it, presumably because of limited administrative personnel.

Enabling legislation has been introduced in six states once and in some cases twice but so far has failed to receive favorable action. In addition to the above there are eight states in which some form of licensing has been or is being actively considered at the present time. This means that a total of 29, or more than half the states in the union, have seriously considered the licensing of sewage plant operators.

Further analysis shows that New Jersey, as mentioned before, was the pioneer in this activity and the first to adopt regulations for licensing in 1919 (enabling legislation 1918). Little further progress was made until 1933 when Connecticut passed an enabling act. In 1934 Michigan established regulations as a health department requirement. These regulations have since been held unenforceable by the State Attorney General and the plan has operated subsequently on a voluntary basis. Before 1937, only three states had adopted any definite plan for qualifying sewage plant operators. Since that year, 12 states have established or will put into effect a license plan before 1941.

The agencies which administer the licensing provisions vary, as shown by the summary, but in the great majority of cases the respective State Health Departments either alone or in cooperation with other state agencies, state associations or groups of operators through representation on boards established to review and examine candidates, have a reasonable jurisdiction and control of the administration of the licensing provisions. The State Health agency is believed to be the logical one either to administer the regulations where mandatory, or to serve in a representative capacity on a reviewing board where the licensing is on a voluntary basis. The duties of such agency require not only close contact with the operator and the plant, but also consideration of the broader aspects of general state policy and the common good.

At least six states and probably more having regulations have incorporated therein the grandfather clause which gives operators as of date of adoption, some form of exemption from compliance with the requirements. This is practically the only basis on which any license legislation can be passed so that the regulations will not be retroactive. The operators of all plants would eventually come under the plan as replacements become necessary but no hardship is worked on operators already employed. In the case of voluntary licensing, the grandfather clause is not needed.

It is found generally that licenses are renewable either annually or on a two year or longer basis. In most instances a specific provision for revocation of the license or approval is given. When licenses re-

Summary of Sewage Plant Operator Licensing 1940

State	Plan in Effect	Date Started	Voluntary or Required	Renewal	Revocable	"Grandfather" Clause	Agency Administering Regulations	Remarks
Alabama	No							
Arizona	Yes	1940	Voluntary	1 yr.	Yes	Yes	State Board of Health, Sewage and Water Works Association	Starting October 6, 1940
Arkansas	Yes	1940	Voluntary	2 yrs.	Yes	No	Water and Sewage Conference Bd. includes representative U. of Arkansas and State Board of Health	Three grades of operators
California	Yes	1936	Voluntary	5 yrs.	Yes	Yes	Sewage Works Association	Legislation failed passage at 2 last sessions
Colorado	No							
Connecticut	Yes	1933	Required	No	Yes	No	State Department of Health	Approval of qualifications for each plant
Delaware	No							
Florida	Not yet						State Department of Health	Legislation passed last session. Plan start in few months
Georgia	Yes	1940	Voluntary					Starting at Ga. Water and Sew. Sch. 10/16–19, 1940
Idaho	No							
Illinois	Yes	1939	Voluntary	1 yr.		No	St. Health Dept. San. Water Board	"Certificate of Competency" 3 grades or classes
Indiana	No							Bill failed of passage 1939. To re-introduce in 1941
Iowa	No							Operators organized to secure legislation—failed last session
Kansas	No							Awaiting legis. authority
Kentucky	No							Have authority but not used yet
Louisiana	No							
Maine	No							
Maryland	No							
Massachusetts	No							Civil service where municipality desires
Michigan	Yes	1934	Voluntary	No	Yes	Yes	State Dept. of Health	First required by regulation of Dept. Declared unenforceable—now voluntary
Minnesota	No							Being considered
Mississippi	No							
Missouri	No							Being considered first for water works operators—then sewage
Montana	No							

SUMMARY OF SEWAGE PLANT OPERATOR LICENSING 1940—*Continued*

State	Plan in Effect	Date Started	Voluntary or Required	Renewal	Revocable	"Grandfather" Clause	Agency Administering Regulations	Remarks
Nebraska	No							
Nevada	No							
New Hampshire	No							
New Jersey	Yes	1919	Required	1 yr.	Yes	Yes	State Dept. of Health	Eight grades or classifications
New Mexico	No							Has been considered but too few full time operators
New York	Yes	1937	Required	No	Yes	Yes	Public Health Council	Three grades of operators
No. Carolina	No							Starting certification of water works operators
No. Dakota	Prob. Yes	1940	Voluntary				Water and Sewage Works Conference	Convention Sept. 26–28, 1940 to act on voluntary certificates of competency
Ohio	Yes	1937	Required	No	Yes	Yes Initially	State Health Department	Four classes of operators
Oklahoma	Yes	1939	Voluntary	2 yrs.	Yes	No	State Health Dept.—Okla. A. & M. College Water and Sewage Conference	
Oregon	No							Being considered—schools held annually
Pennsylvania	No							Bill prepared by Water and Sewage Works Assns.
Rhose Island	No							Recommended to 1940 legislature
So. Carolina	No							Hope to have certification handled by Water Works Association
So. Dakota	Yes	1940	Voluntary				Board of Water and Sewage Works Conference, Inc., State San. Engr.	Planning to start soon
Tennessee	No							Plan to start as soon as more modern plants constructed
Texas	Yes	1938	Voluntary	*a.* 5 yrs. *b.* 3 yrs. *c.* 2 yrs.		No	State Dept. Health—Water Works and Sewage short school—State Dept. Education	Three grades of operators
Utah	No							
Virginia	No							
Vermont	No							
Washington	No							Being considered—schools held annually
West Virginia	Yes	1939	Voluntary					Certified on request of operator—Legislation passed 1939—required licensing planned 1941
Wisconsin	No							Bill failed passage 1937—further action in near future
Wyoming	No							Being considered

quire renewals, it is not so necessary that a specific means or authority for revocation be established as reconsideration at intervals gives ample opportunity to withhold approval of incompetents. The granting of a license or certificate of qualification without limitation as to period is not considered as satisfactory as a plan providing for renewals.

As to the results of licensing, a plan has been in effect in many of the states for such a short time that definite conclusions cannot be drawn. However, where given a fair trial, the consensus of opinion is that the results have been satisfactory and only in a few cases are changes in the present regulations contemplated.

As a general conclusion of the present status of licensing in the country it is apparent that this means of raising the standards and assuring more competent operating personnel for sewage treatment plants is progressing rapidly. The benefits of such a plan cannot help but accrue to the operator as well as to the municipality and the general public.

In addition, the State Health agency is relieved of much of the recurrent work of training new and frequently incompetent operators and maintaining the plant efficiencies. Some form of licensing has come to stay and we may expect further general application of it throughout the country.

Acknowledgement is made of the helpful assistance and advice in the preparation of this paper by C. A. Holmquist, Director of the Division of Sanitation; A. S. Bedell, Chief of the Bureau of Sewage and Waste Disposal, and A. F. Dappert, Principal Sanitary Engineer of the New York State Department of Health. Acknowledgement is also made of the cooperation of the State Sanitary Engineers in furnishing the desired information which made possible the preparation of the summary of the status of licensing in the country.

DISCUSSION OF "PROGRESS IN THE CONDITIONING OF SEWAGE SLUDGE FOR DEWATERING"*

By Frank Woodbury Jones

Discussion by Harry A. Faber

Research Chemist, The Chlorine Institute, Inc., New York, N. Y.

The many variable factors which influence dewatering of sludge on vacuum filters have been described in a most comprehensive manner by Mr. Jones. This discussion will be devoted specifically to comment on one of those factors: The conditioning chemicals employed. It represents a progress report toward an attempt to evolve procedures which may become somewhat standardized.

A survey has been conducted to determine the operating conditions and results of using ferric chloride, or other conditioning chemicals, at sewage treatment plants which dewater sludge on vacuum filters. While it has not been possible to obtain data from all such plants, that which is so far available appears to be fairly representative and to be worthy of presentation in order to supplement the conclusions stated in Mr. Jones' paper.

A questionnaire was sent to each of 98 sewage treatment plants which have been reported as being equipped with vacuum filters. Replies were received from 61 of these plants, and tabulation of the data is as follows:

Replies	Number of Plants
Have no vacuum filters	4
Filters not in operation	10
Using paper pulp	1
Using alum	1
Using lime	3
Using ferric sulfate	2
Using chlorinated copperas	2
Using ferric chloride	38
Total	61

Thus, of the 46 plants which report the use of sludge conditioning chemicals, 85 per cent employ ferric chloride for the purpose. As those plants reporting seem representative, it appears that this proportion will be maintained when more complete returns are available. Since the sewage treatment plants using conditioning chemicals other than ferric chloride represent special cases and are too few in number to supply very general data, only those plants using ferric chloride will be further considered.

A large number of tabulations can be made of the variety of data

* Presented at the First Annual Convention of the Sewage Works Federation, Chicago, Ill., Oct. 3, 1940.

provided by this survey. Certain items have been selected to illustrate the wide divergence of conditions which obtain in these plants.

1. *Sewage Treatment Process from Which Sludge is Obtained:*

Process	Number of Plants
Plain sedimentation	18
Activated sludge	10
Chemical coagulation	8
Chemical and activated	2

2. *Sewage Treatment Process Related to Per Cent Solids in Sludge Before Filtering:*

Process	Per Cent Solids in Sludge		
	Maximum	Minimum	Average
Plain sedimentation	16.0	2.9	9.3
Activated sludge	10.3	0.7	4.7
Chemical coagulation	10.0	1.8	6.3
Chemical and activated	7.3	3.8	5.6

However, it is not the sewage treatment process which necessarily determines the solids content of the sludge to be filtered. Another variable factor is introduced by treatment of the sludge after it is settled but before it is dewatered.

3. *Treatment of Sludge Prior to Conditioning:*

Type of Sludge	Number of Plants
Raw, fresh	8
Raw, stale	2
Raw, concentrated	7
Digested	16
Digested, elutriated	5

While the average per cent of solids in these types of sludges may reasonably be related to average yields of filter cake obtained, such relation is highly questionable. It is necessary to consider the extreme variations of maximum and minimum figures which comprise the averages. When this is done, it will be apparent that many factors other than per cent of solids determine the yield of filter cake.

4. *Solids in Sludge and Filter Cake Yield Related to Type of Sludge Filtered:*

Type of Sludge	Per Cent Solids in Sludge			Filter Cake, Lb./Sq. Ft./Hr.		
	Max.	Min.	Avg.	Max.	Min.	Avg.
Raw, fresh	10.9	0.6	4.7	15.0	1.0	5.2
Raw, stale	6.0	5.0	5.5	5.0	3.0	4.0
Raw, concentrated	14.0	2.0	7.5	15.5	1.2	5.6
Digested	16.0	4.0	8.5	14.8	2.5	8.5
Digested, elutriated	12.0	2.9	7.9	7.5	5.4	6.6

A comparison of the type of sludge treated with the use of ferric chloride alone or in conjunction with lime illustrates one of the factors which must be considered. It should be noted that the data show almost all of those plants which use ferric chloride alone, filter sludge at a pH 7.0 or less; while those plants using both ferric chloride and lime filter sludge at pH 7.0 or higher.

5. *Type of Sludge Filtered Related to Chemicals Employed:*

Type of Sludge	Number of Plants	
	Ferric Chloride	Ferric Chloride + Lime
Raw, fresh	3	5
Raw, stale		2
Raw, concentrated		7
Digested	1	15
Digested, elutriated	5	

It is difficult to determine any clear relation between the effect of pH and the life of filter cloth, since the data submitted shows wide variation on this point.

6. *Life of Filter Cloth as Related to pH of Sludge Applied to Filters:*

Applied	Number Plants	Life Filter Cloth, Hours			Filter Cloth Material		
		Max.	Min.	Avg.	Wool	Cotton	Unknown
Below pH 7.0	7	4,000	200	1,900	4	1	2
Above pH 7.0	31	4,000	100	500	3	20	8

Inspection of the data to learn the form of ferric chloride employed, illustrates that the choice is determined by size, location, and facilities of the treatment plant rather than by the type of sewage treatment.

7. *Form of Ferric Chloride Used as Related to Treatment Process:*

Process	Number of Plants Using		
	Anhydrous	Crystal	Liquid
Plain sedimentation	7	1	10
Activated sludge	5	3	2
Chemical coagulation	5	1	2
Chemical and activated	1	1	–

Thus, not only are there many types of sewage sludges produced in modern sewage treatment processes, but the subsequent handling of such sludges prior to conditioning and dewatering introduce many variable factors. Certainly there is little apparent correlation between conditioning practices and results reported by various plants. It is not necessary, because of these variations, to conclude that each plant must be considered as an entirely separate problem.

The data provided in this survey of sludge conditioning chemicals does indicate a need for standardized procedure. It is submitted that, through concerted study of this problem, a degree of standardization, a considerably improved technique, and a better evaluation of sludge conditioning should be attained. Considerable study has been devoted to the development of vacuum filtration as a practical, modern method of sludge dewatering. Further study to develop sludge conditioning practice to a degree of greater efficiency and greater economy appears to be a present need.

Industrial Wastes

RECENT TRADE WASTE DISPOSAL METHODS *

By E. F. Eldridge

Research Associate, Engineering Expt. Sta., East Lansing, Mich.

Considerable progress has been made in recent years in the development of methods of treatment for industrial or trade wastes. Many of these methods have been tried on a full scale basis. Some of them have failed utterly to meet expectations and have been abandoned. Others have proven partially successful and have continued in use although not always meeting the desired requirements. A few have been entirely successful.

In most of the cases where failure has resulted during full scale operations, the fault has not been with the process. Perhaps the most outstanding reason for failure is the lack of understanding and care in the operation of the plant. Like some sewage treatment plants, industrial waste treatment plants in many cases are supposed to be largely automatic. It is generally expected that they will take care of themselves.

Methods may be developed with utmost care, experimentally, the plants may be constructed to conform to the results of the experimental work, and yet they may fail because of lack of operation. Perhaps those who develop these methods are somewhat to blame for the existence of this condition. No full scale plant will ever receive the same attention as is given an experimental plant. This factor must be given consideration in the development of the methods. Reasonable attention to operation, of course, can certainly be expected.

A second reason for failure is the lack of proper study prior to the installation of the treatment process. Each individual factory presents a different problem and must be given at least a complete survey. In most cases a pilot plant study should be made before the full scale plant is designed.

I believe that I can safely say that most of the failures I have observed can be traced to either a lack of operation or to an incomplete understanding of the problem. In the majority of other cases, failure has been due to an overloading of the plant either because of faulty design or an unexpected increase in the factory production.

A method of treatment, to be adapted to an industrial waste, must meet a number of requirements of which the more important are as follows:

1. It must require a minimum of *technical* attention. Unless the

* Presented at the First Annual Convention of the Sewage Works Federation, Chicago, Ill., Oct. 5, 1940.

plant is a large one, trained help is not usually available. This does not mean, however, that the process should be automatic or even approaching that stage. Usually, the more attention required, the more is given. The required operation should not be of too technical a nature.

2. It must be inexpensive in construction. Industries cannot afford to pay for waste treatment on the same basis as a municipality pays for sewage treatment.

3. The efficiency of the process must be high. Many of the organic industrial wastes have B.O.D. values much greater than sewage. The process must be capable of reducing this high B.O.D. to values comparable to those of sewage treatment plant effluents.

4. It must be capable of withstanding the shocks of widely varying volumes and strength of waste since the flow and strength of industrial wastes generally vary over a wide range.

This is rather a lengthy introduction to the subject which I have been asked to discuss, namely, "Recent Trade Waste Disposal Methods." I have not attempted to include all of the recent developments in industrial waste treatment in the discussions which follow, since this would be impossible in the time allotted. I have selected a few which appear to be of general interest.

Industrial waste treatment methods in most cases, and especially as concerns organic wastes, are adaptions of sewage treatment processes. As you know, there are two general divisions of these processes. We usually name these divisions primary and secondary treatment. Primary treatment consists of screening, grit removal, coagulation, sedimentation and sludge disposal. Secondary processes are usually oxidation processes, such as biological filtration and activated sludge. There are two processes of industrial waste treatment involving primary treatment facilities which I have selected for discussion. The first is a coagulation and sedimentation plant for paper mill wastes.

Paper Mill Waste Treatment Plant

Waste treatment in the paper industry in the past has consisted largely of attempts at recovery of usable materials. Many different types of so-called "save-alls" are in use in the different mills. The amount of usable material in a mill waste depends upon the type of paper made in that mill. Mills producing high grade paper must wash away all foreign materials and cannot use some of the finer fibers which are lost in the washing process and in the white water from the machines. Board mills making boxes, cartons, asbestos board, etc. can, and do, include much foreign material in the paper in addition to fiber. In these cases recovery can be carried much further than in the high grade mill.

During the past year a board mill in Michigan has installed treatment facilities for their wastes. These wastes had previously been dis-

charged to the municipal sewage plant and had caused unlimited difficulties in that plant. There are two paper machines in this mill. One, known as a wet machine, manufactures a tar board used for waterproof strips in automobiles and elsewhere. The other machine (a dry machine) produces numerous kinds of box board, wrappers, asbestos board, etc. Two treatment plants were built, one for each machine. This was necessary since the recovered material was to be reused and the tar board sludge could not be mixed with the material from the other machine.

Each plant consists of an alum machine, flash mixer, coagulation tank and settling tank. (See Fig. 1.) The coagulation tanks are each

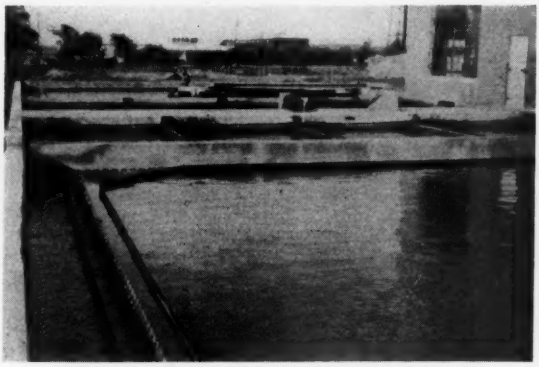

FIG. 1.—Treatment plant, paper board mill.

divided into four compartments in which are located Dorr paddle wheel flocculators. The waste flows through each compartment in series. The settling tank is a square Dorr clarifier with center feed and outlet weirs about the outer edge. Table I gives pertinent information con-

TABLE I.—*Paper Mill Treatment Plant*
Monroe Paper Products
Capacity of each coagulation tank—69,000 gal.
Capacity of each settling tank— 187,500 gal.

	Paper Machine			Wet Machine		
Waste flow, gal. hr.	85,600			15,200		
Coagulation period	50 min.			5.0 hr.		
Settling period	2.2 hr.			12.3 hr.		
	Inf. P.P.M.	Eff. P.P.M.	Red. %	Inf. P.P.M.	Eff. P.P.M.	Red. %
Suspended solids	426	14	96.5	1552	24	98.4
Fiber	362	10	96.5	1324	24	98.2
B.O.D.	116	42	63.8	126	46	63.5
Fiber recovered daily, tons	5.8			2.0		
Solids recovered daily, tons	6.9			2.3		
Alum used	50 p.p.m.			95 p.p.m.		
Alum used daily	600 lb.			400 lb.		

cerning this plant. The two sections were made of the same capacity. Due to the lower rate of flow from the wet machine, the detention periods for this waste are much greater than necessary.

A total of about 1000 pounds of alum are used daily. The paper machine recovers almost 7 tons of usable material, the wet machine 2.3 tons or a total of 9 tons. These values are somewhat higher than the average, which is between 5 and 6 tons.

Beet Sugar Factory Waste Treatment

The second plant involving primary treatment is in connection with beet sugar factory waste at the Monitor Sugar Company, Bay City, Michigan. I hesitate to mention beet sugar factory waste, since for the past five years most of the bulletins coming from our Station have had papers on this subject. However, this is one of the important waste producing industries, especially in Michigan where the load contributed by beet sugar factories in their season is about equal to one-half of the domestic sewage load produced by the entire state.

Among the recent developments in this field is the completion of what we believe to be the first beet sugar factory waste treatment plant, built along standard lines, in the world. Fig. 2 shows the general arrangement of this plant. It consists of structures for screening, grit removal, coagulation and sedimentation. Standard commercial equipment is used throughout the plant. The problems presented in each case were entirely different than those encountered in the sewage treatment field. Table II shows the 1939 results.

The plant handles from 5 to 6 m.g.d. The screen is of the rotary type, removing about 30 cubic yards of screenings daily (6 cubic yards per m.g.). The three grit chambers are equipped with Link-Belt scrapers. The grit is dropped onto an endless belt and removed to a pile. About 33 cubic yards of grit are removed daily (6.5 cubic yards per m.g.).

Coagulation is accomplished by mixing the wastes from the factory. The coagulation period is 20 minutes. The settling period is 80 minutes. Sludge is pumped every 4 hours. About 36,000 gallons of sludge is removed daily containing on the average 15.5 per cent solids. The sludge does not digest. It is removed to a large pond until provision is made for drying on the vacuum filter. This plant removes about 32 tons of solids on the dry basis daily. The removal of suspended solids was 91.4 per cent and B.O.D., 61.2 per cent.

Other beet sugar factories in Michigan are operating or in the process of constructing waste treatments plants which are similar in principle to the Monitor plant, but which deviate in some respects in construction. In two of these plants a portion of the treated waste is reused in the factory for transporting beets in the flumes. Several years ago there was considerable opposition to reuse of water in the beet sugar factories. At present the tendency seems to be toward more and more reuse combined with partial treatment.

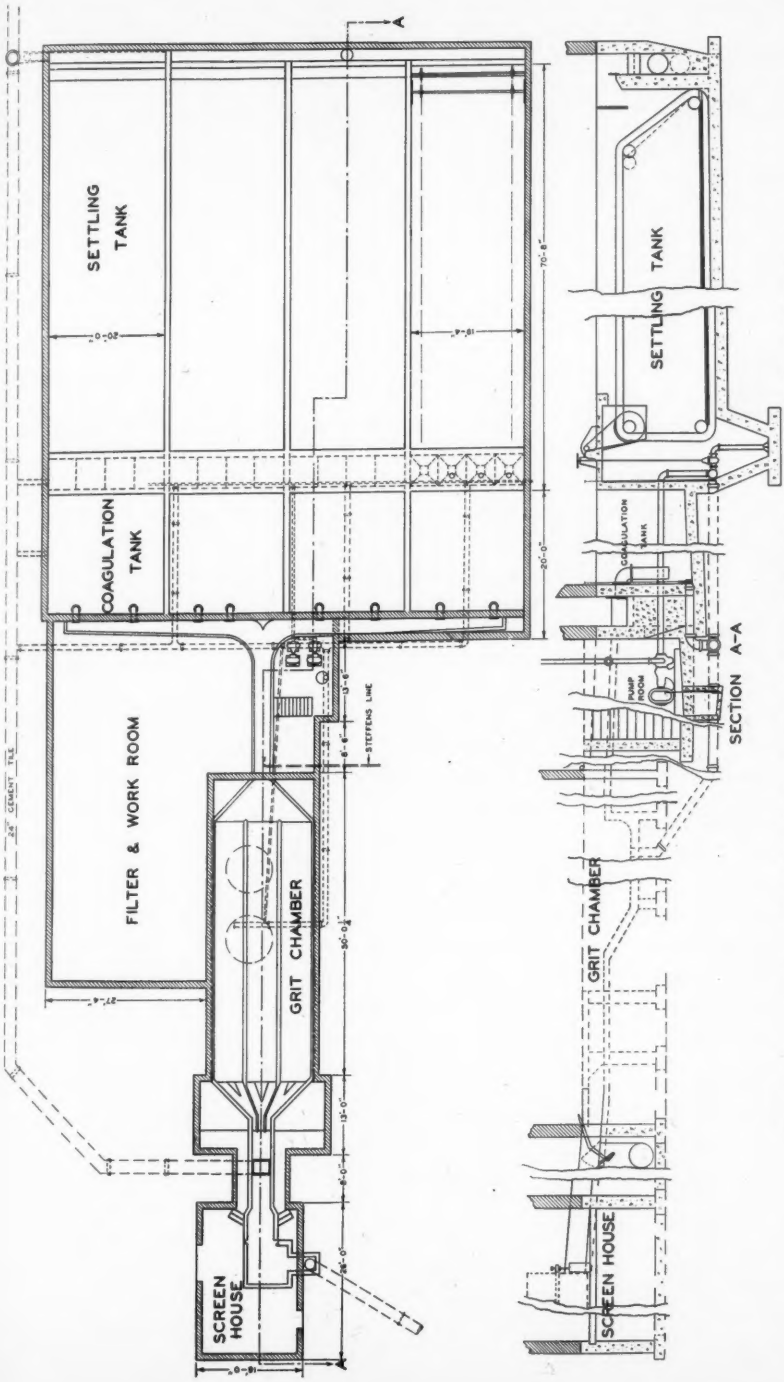

FIG. 2.—Layout of complete plant for beet sugar factory waste treatment, Monitor Sugar Company.

TABLE II.—*Beet Sugar Waste Treatment*
Monitor Sugar Company

Volume of waste	5.2 m.g.d.
Screenings removed	30 cu. yds.
Volume of sludge	36,000 gal. daily
Solids in sludge	15.5 per cent
Suspended solids influent	1607 p.p.m.
Suspended solids effluent	141 p.p.m.
Suspended solids removed	91.4 per cent
B.O.D. influent	919 p.p.m.
B.O.D. effluent	358 p.p.m.
B.O.D. removed	61.2 per cent

BIO-FILTRATION

Among the secondary or oxidation processes of recent development are several which affect industrial waste treatment processes. One of the outstanding of these is the so-called "bio-filtration process" which has resulted from original suggestions of Halverson and Jenks.

The trickling filter has for a long period been more or less standard equipment for the treatment of organic industrial wastes, such as are produced by milk plants, canneries, tanneries, etc. The efficiency of this type of treatment, however, has not always been sufficient to meet all requirements. The basis of design for the standard filter varies from 80 to 120 cubic feet per pound of B.O.D. applied. Due to the high B.O.D. of these wastes, large filter areas are required if an effluent of the desired quality is to be obtained.

The bio-filter makes use of two principles which have a marked effect on two of these main objections to the standard filter. First the waste is applied at a higher rate and increased load, thus decreasing the size of filter required. Second, the effluent may be recirculated as many times as desired, thus increasing the efficiency for B.O.D. removal. The rate of application to the standard filter is from 1 to 2 m.g.a.d. and the loading 80 to 120 cubic feet of media per pound of B.O.D. The rate to the bio-filter is from 16 to 30 m.g.a.d. (average 20 m.g.a.d.) and the loading for most industrial wastes about 30 cubic feet per pound of B.O.D.

I have taken the milk waste filter as an example to show more clearly the difference in the two types of filters. Table III shows the loading

TABLE III.—*Standard Filter for Milk Waste*

Plant No.	Volume of Waste, Gallons	Media per Lb. B.O.D. Cu. Ft.,	Influent, P.P.M.	B.O.D. Effluent, P.P.M.	Reduction, Per Cent
1	28,000	31.5	820	340	58.5
2	20,370	83.0	1140	270	76.3

and efficiency of two standard milk waste filters in Michigan. Filter No. 1 is obviously overloaded since the B.O.D. load is 1 pound per 31.5 cubic feet. The efficiency is 58.5 per cent. No. 2 is at about design

loading (83 cubic feet per pound). The efficiency is 76 per cent. The effluent B.O.D.'s are greater than normal raw sewage in both cases.

Filter No. 1 was converted to the high-rate recirculating type by making the changes shown in Fig. 3. These changes necessitated the installation of a higher capacity pump and rotary distributor. A diversion weir box was constructed at the end of the settling tank and connected by a tile line to the inlet end of the storage tank. This weir keeps the level of water in the storage tank constant. The quantity of effluent discharged is equal to that of the influent. The storage tank has a capacity for about one half day's flow of raw waste. The rate of application is 20 m.g.a.d.

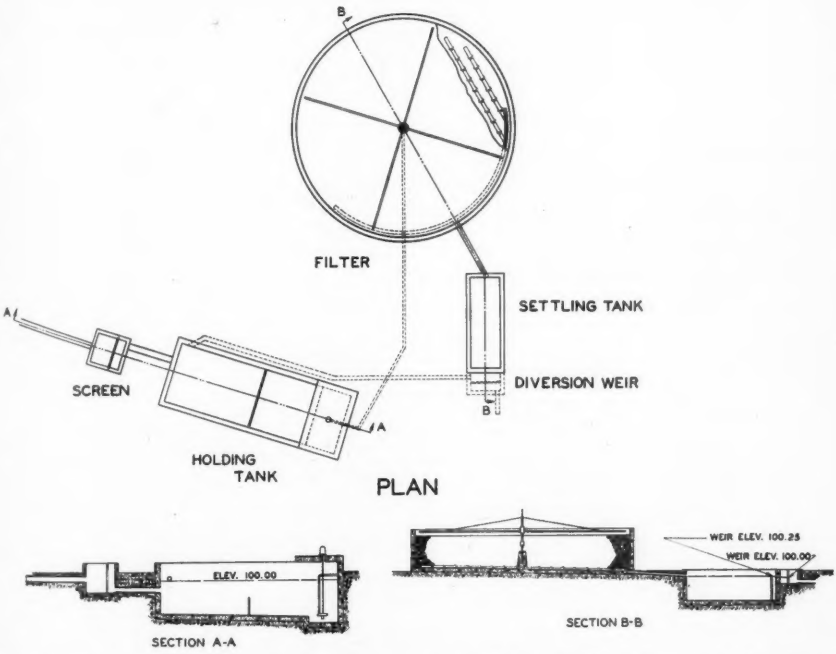

FIG. 3.—Changes necessary to change Perrington standard filter to high rate recirculating filter.

Table IV shows the results of the operation of this filter. The waste is the same as previously applied, the filter is the same size, but the efficiency has been increased from 58.5 to an average of 90.6 per cent. The average B.O.D. of the effluent is 46 p.p.m.

The high-rate recirculating filter will undoubtedly be adapted to other industrial wastes in place of the standard type. Warrick in "Methods of Treating Cannery Waste" has recommended the recirculating principle for filters for canning factory waste treatment. Standard filters can usually be easily converted to the recirculating type.

TABLE IV.—*Recirculating Filter for Milk Waste*
(5-Day B.O.D.)

Date	Raw Waste, P.P.M.	Filter Influent, P.P.M.	Filter Effluent, P.P.M.	Final Effluent, P.P.M.	Reduction, Per Cent
Sept. 6	353	105	28	27	92.4
7	675	133	34	38	94.4
8	350	183	70	70	80.0
9	893	57	34	48	94.1
11	540	111	44	42	92.2
12	573	84	45	47	91.8
13	407	103	54	50	87.7
14	413	76	44	48	90.0
15	713	98	46	49	93.2
Averages	537	106	44	46	90.6

BIO-CHEMICAL TREATMENT

Another comparatively recent process of waste oxidation is the bio-chemical treatment method developed in the Guggenheim Bros. laboratories. The bio-filter just discussed is a variation of the standard filter. The bio-chemical process is a variation of the activated sludge process, or rather, it combines the manipulation of activated sludge with those of chemical floculation.

Fig. 4 shows the general arrangement of units required for a plant

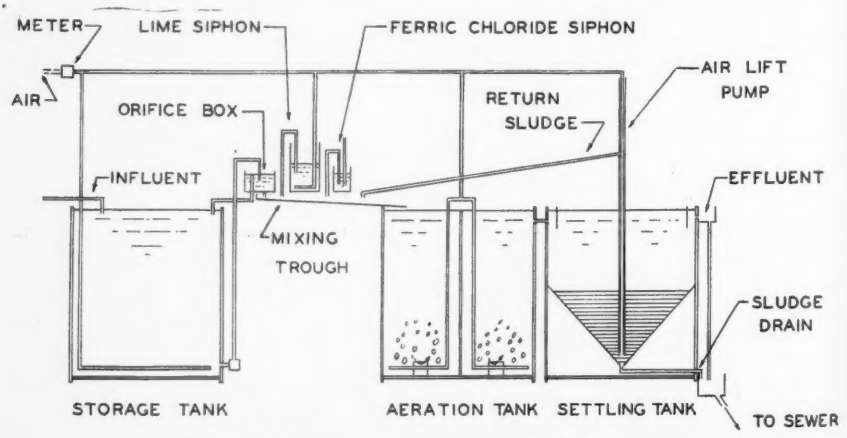

FIG. 4.—Arrangement of units of biochemical process.

using this process. You will notice that the first unit is a storage tank. Industrial wastes in many cases require a storage tank to equalize the waste and to allow the operation of the treatment units for the full day. Air is applied in this tank to keep the wastes from becoming septic and to prevent sedimentation. The chemicals are applied in some sort of mixing device where the return sludge is also added. The mixed liquor

is then passed through aeration and settling tanks. A portion of the chemical sludge is returned to the mixing unit. Excess sludge is dried on sand beds or lagooned.

This process has been applied to milk and cannery wastes with considerable success. Even the very strong cheese factory wastes have been successfully treated. It combines the advantages of chemical treatment with the oxidizing action of activated sludge. There is considerable biological activity which is due to a somewhat different flora than commonly encountered in activated sludge.

The principle advantages are:

1. A much shorter aeration period than activated sludge.
2. The sludge does not bulk even with excess loading, high carbohydrates and sudden shocks.
3. The process is much more efficient in B.O.D. removal than chemical treatment and, for the same aeration period, than activated sludge.
4. It is adaptable to wastes up to 3000 p.p.m. B.O.D.
5. By applying the principle of recirculation, extremely low effluent B.O.D. values are possible.

I have prepared Table V to show what has been accomplished by the use of this process with strong cheese factory wastes. The B.O.D. of

TABLE V.—*Bio-Chemical Treatment of Cheese Factory Waste*

Aeration period, hours	4.5
Lime, p.p.m.	400
Ferric chloride, p.p.m.	85
pH	7.5
Total solids, influent, p.p.m.	5792
Total solids, effluent, p.p.m.	1580
B.O.D., influent, p.p.m.	3400
B.O.D., effluent, p.p.m.	400
Reduction, per cent	88.2
Suspended solids mixed liquor	3200
Sludge index	70

the influent averaged 3400 p.p.m. and the reduction was 88.2 per cent. Of course, the final effluent B.O.D. was high and in some cases a further reduction may be necessary. Values below 25 to 50 p.p.m. are possible by recirculation of the effluent.

FABRICATED STEEL STRUCTURES

I made the statement at the start, that cost is an important item in industrial waste treatment. This is especially true of treatment for small industries. In order to meet this requirement the Lancaster Iron Works have a division in waste research for the purpose of design, construction and operation of fabricated steel structures for industrial waste treatment.

The so-called "package" unit, Fig. 5, shows a fabricated steel treatment plant set up at a milk products factory. The first or taller unit is a hopper bottom tank for aeration of the waste. The second is a hopper bottom settling tank. Chemical dosing equipment, chemicals, air compressor, pumps, and all other necessary equipment is housed in the lower portion of the units under the hopper of the tanks. These units are designed and built at the factory, shipped to the location, and set up. About 24 hours is required to set up a plant and place it in operation after it arrives on the site.

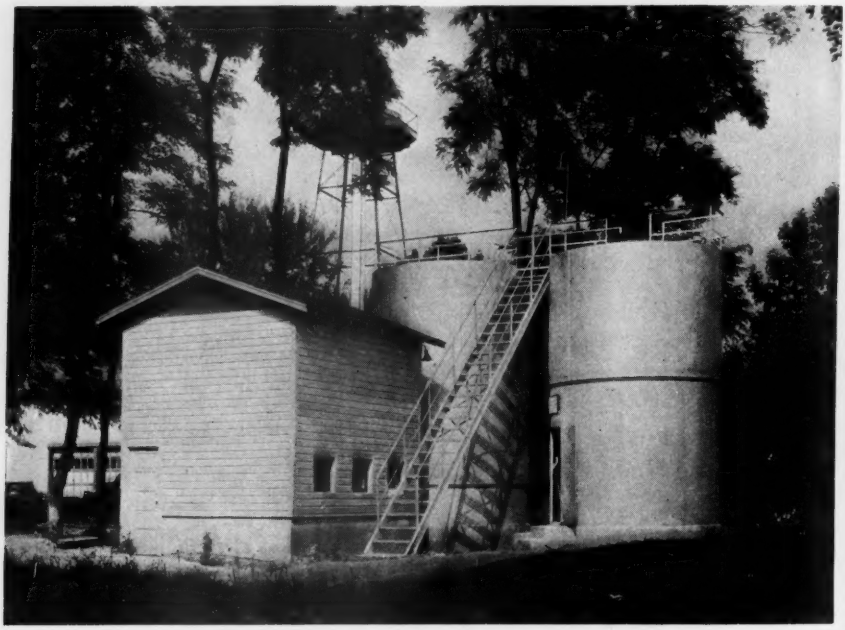

FIG. 5.—Fabricated steel units at milk products plant.

Sludge digestion tanks, chemical treatment units, activated sludge units, etc. are processed of steel in small and large units. They are particularly adapted to industrial wastes since they are flexible and more in keeping with other industrial equipment. The life of the steel tank with proper care is said to be from 20 to 25 years. The cost is about 50 per cent of that of concrete structures of the same capacity.

I have only mentioned a few of the many recent developments in trade waste disposal. New processes and improvements in old ones are constantly appearing in the literature. But in spite of the large amount of work already done, the matter of industrial waste treatment is still in the pioneering stage.

EXPERIMENTAL TREATMENT OF CITRUS-CANNERY EFFLUENT IN FLORIDA *

By Harry W. von Loesecke,† George N. Pulley,† Arthur J. Nolte † and Harry E. Goresline

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The disposition of industrial wastes has become a problem of increasing seriousness during the past few years. Much has already been accomplished in the treatment of wastes from food plants, particularly dairy, corn, pea, tomato, packing house and beet sugar wastes, but nothing has been offered regarding the proper treatment of wastes from citrus canning plants. One possible explanation for this may be that such plants are usually located in more or less sparsely inhabited areas and the public health aspects of the problem were not in general considered of commanding importance. However, with the steady growth of the citrus products industry, along with the fact those regions in which citrus canneries are located have become a winter playground (especially in Florida), the necessity of a better method of waste disposal, particularly for some plants, has become apparent.

In Florida, the problem of proper disposal of waste waters from citrus canneries has been recognized by the canners themselves and they have undertaken constructive work to remedy the situation. The researches reported in this paper were made possible by the financial cooperation of the Florida Canners' Association, and with the engineering advice of the Florida State Board of Health.

At the present time, waste waters from citrus canneries in Florida are disposed of by:

A. Emptying into Lakes.—As shown later in this paper this method may cause pollution and destruction of fish life. This danger is particularly present when the body of water is of insufficient area to properly dilute the waste.

B. Handling by City Sewerage System.—In some instances this has caused damage to pumps and piping, clogging of sand beds and excessive foaming in Imhoff or primary settling tanks. Most cities in Florida are reluctant to handle such wastes.

C. Primary Settling Tanks.—This method has not proven satisfactory because retention time is too short and the material shows little tendency to flocculate and settle. The addition of chemicals to encourage flocculation has not yielded effluents of greater purity. Even when the wastes are filtered clear (a practice that would be economically impossible) no significant improvement is shown in the 5-day biological oxygen demand (B.O.D.), or oxygen consumed value.

D. Flooding of Waste Lands.—To use this method, an isolated sec-

* Food Research Unit Contribution No. 513.

† U. S. Citrus Products Station, Winter Haven, Florida.

tion of land of sufficient area and with a low water table of favorable porosity is necessary. Intermittent application followed by discing is required to prevent ponding. When ponding occurs without preventative measures, conditions become favorable for mosquito and fly breeding. Some canneries using this method of disposition have obtained satisfactory results. Unfortunately, all canneries are not located so that this method can be used.

E. Disposing in Tide-water Rivers.—This practice is, of course, limited to those canneries located on the coast. The few canneries so located have not as yet experienced any difficulties, although the danger of polluting shell fish must be kept in mind.

Nature and Quantity of Liquid Wastes

These factors will vary according to the size of the cannery and whether the plant is packing sections, juice or both. From Table I it

Table I.—*Analyses of Screened Cannery Effluents*

	Plant No. 1	Plant No. 2	Plant No. 3	Plant No. 4
Type of Pack	Sections and juice	Sections	Juice	Sections
Total Solids	1403	4084	672	3550
Organic Solids	1189	3633	551	3246
Inorganic Solids	214	451	121	304
Suspended Solids	61	248	171	287
pH	7.2	6.1	6.5	5.6
5-Day B.O.D.	583	2000	343	1722

may be seen that plants packing sections alone have stronger effluents than those merely packing juice. The quantity of waste waters will also vary from approximately 30,000 or 40,000 gallons per 10-hour day to as much as nearly half a million gallons per 10-hour day. A survey was made of one large cannery packing 4,000 cases of No. 2's per 10-hour day and having an effluent discharge of 226,000 gallons per day of 10 hours. This is, therefore, at the rate of 56.5 gallons per case of No. 2's. From conversations with other canners this is just about what might be expected as an average for citrus canneries; some believed that it ran about 50 gallons per case.

The waste waters from the particular cannery studied may be roughly grouped into seven different kinds:

1. Can-cooler overflow.
2. Fruit-washing waste water.
3. Peeling-table waste water.
4. Sectionizing-table waste water.
5. Exhaust-box overflow.
6. Flushing water from floors, etc.
7. Waste alkali from peeling tanks.*

* This type of waste would be met with only in plants sectionizing fruit. Alkali tanks are generally dumped two or three times a week depending upon the extent of pack. In some instances, the material is emptied into cess pools.

Difficulty in sampling made it impossible to keep separate all seven groups. It should be pointed out, too, that the values given are not absolute and should be used for comparative purposes only.

1 and 2. *Can-cooling Tanks and Fruit-washing Waste Waters.*—The overflow from the cooling tanks is used to wash the incoming fruit and part of this combined waste water is pumped to the peeling tables for flushing purposes. The combined waste waters from cooling tanks and fruit washer amounted to about 2200 gallons per hour with an oxygen consumed value of 45 parts per million (p.p.m.), a 5-day B.O.D. of 20 p.p.m. and a pH of 7.2.

3. *Peeling Tables.*—The plant had 64 peelers. It was not possible to measure the volume of waste waters from these tables, but as stated above the water used here is part of that from the cooling tanks and fruit washer. The waste waters from the peeling tables showed an oxygen consumed value of 560 p.p.m., a pH of 7.2 and a 5-day B.O.D. of 380 p.p.m.

4. *Sectionizing Tables.*—The plant had 230 sectionizers. The waste water from the tables had an oxygen consumed value of 2840 p.p.m., a pH of 4.5 and a 5-day B.O.D. of 2480 p.p.m. The combined volume of waste waters from the peeling and sectionizing tables amounted to about 15,800 gallons per hour.

5. *Exhaust Box Overflow.*—This amounted to approximately 45 gallons per hour with an oxygen consumed value of 1280 p.p.m., a pH of 6.1 and a 5-day B.O.D. of 1000 p.p.m.

Daily samples * of the effluent from this plant, over a period of about six months, showed the oxygen consumed value to vary from a minimum of 150 p.p.m. to a maximum of 1440 p.p.m.; and 5-day B.O.D. from a minimum of 100 p.p.m. to a maximum of 1400 p.p.m.

The composition of waste waters from citrus canneries consists chiefly of inorganic salts and organic solids (organic acids, pectin and sugars). Of the total solids, from 2 to 94 per cent consist of sugars (calculated as reducing sugars) and from 0.04 to 0.5 acid as citric. The nitrogen content is very low, amounting to only about 10 p.p.m.

The waste waters are usually quite unstable (the relative stability averaging approximately 30 per cent) and rather quickly undergo decomposition giving rise to offensive odors. This is especially true where decomposition takes place under anaerobic conditions, the septic material having an odor not unlike that of an extremely dirty hog pen.

Upon standing, most of the suspended material in the fresh waste flocculates, but the floc does not readily settle: part rises to the surface, part remains in suspension and part will settle. When septic, the floc generally rises to the surface.

Experimental

To learn the extent of pollution of lake water by citrus cannery effluents, eight lakes in the vicinity of Winter Haven, Eagle Lake, Dundee

* These were composites of hourly samples.

and Haines City, Florida, were sampled once a month for 13 months. Samples were taken at approximately the center of the body of water and five feet beneath the surface. Samples for bacteriological examinations were taken just beneath the surface. Sampling was thus accomplished some distance from the outfalls of the canneries, the outfalls being located at the shore or in canals connecting many of the lakes. Sludge deposits were sometimes quite noticeable near the outfalls. In one canal receiving waste waters gassing was prevalent, especially during warm weather. Since there is no current in the canals connecting the lakes, flow of water depends upon wind direction.

Methods of analysis were those given in *Standard Methods of Water Analysis of the A. P. H. A.*, Seventh Edition.

Space will not permit presentation of data from all the lakes sampled, but results are given for three. Some of the data for the lake at Dundee are plotted in Fig. 1. Lake Silver was taken as a control; this

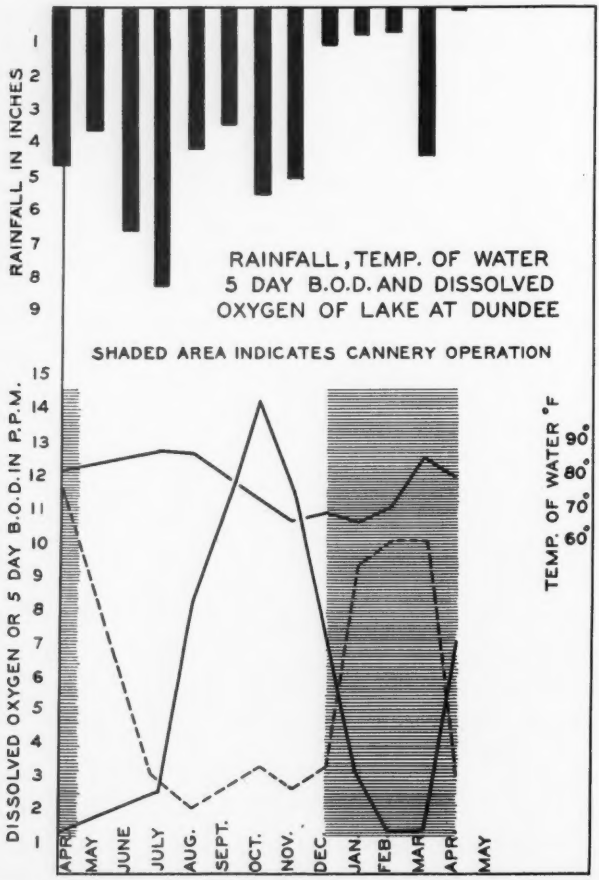

FIG. 1.

body of water has never received any cannery effluent. Upon this lake is located a public bathing beach. The data from the pond at Florence Villa is given because this shows what takes place after citrus cannery effluent is no longer allowed to enter a small body of water. After April, 1937, no effluent was conducted to this pond. In examining the tables it should be borne in mind that in general the lakes received citrus cannery effluent from about December to April.

Referring to Tables II to IV, the most important factor is dissolved oxygen. If a small amount of organic matter is mixed with the water

TABLE II.—*Condition of Water in Lake at Dundee*

Approximate Area = 19.6 Acres
Approximate Volume Water = 77,000,000 Gallons

	April 1937	May 1937	June 1937	July 1937	Aug. 1937	Sept. 1937	Oct. 1937	Nov. 1937	Dec. 1937	Jan. 1938	Feb. 1938	March 1938	April 1938
Temp. Water, ° F.	81	—	—	86	86	—	72	66	68	66	70	84	79
Total Solids, P.P.M.	294	—	—	189	201	—	160	162	207	183	200	250	218
Organic Solids, P.P.M.	192	—	—	85	121	—	120	70	182	92	105	160	113
Inorganic Solids, P.P.M.	102	—	—	104	80	—	40	92	25	91	95	90	105
Suspended Solids, P.P.M.	2	—	—	15	20	—	19	13	6	8	14	13	18
pH	6.88	—	—	7.38	7.90	—	7.65	7.81	7.10	6.10	6.10	7.40	6.93
Dissolved Oxygen, P.P.M.	1.3	—	—	2.4	8.2	—	14.2	11.4	7.2	3.0	1.3	1.3	7.0
5-Day B.O.D., P.P.M.	11.6	—	—	2.8	2.0	—	3.3	2.7	3.3	9.2	10	10	2.8
Bacteria per c.c.													
20° C.	1100	—	—	24	183	—	210	560	4,150	34,800	2,000	27,900	7,400
37° C.	1100	—	—	14	82	—	215	830	3,470	17,900	2,500	33,000	6,000
Coliform Group	40	—	—	0	<1	—	0	4	1,000	100	230	100	100
Total Rainfall, in.	4.87	3.76	6.80	8.44	4.27	3.50	5.55	5.07	1.16	0.94	0.87	4.48	0.09

the natural oxygen content will take care of the load and no ill effects will be noted. However, if organic material is added to a point where the oxygen is depleted it will mean the destruction of aquatic life, and putrefactive action will soon give rise to a public health nuisance. It is generally conceded that while any dissolved oxygen remains, there should not be "putrefaction." It should be added, however, that practically any value below 50 per cent saturation is likely to be accompanied at times by malodorous conditions. Such a condition existed for a time in the pond at Florence Villa.

The amount of dissolved oxygen in water necessary to support fish life seems to be a matter of some dispute. The quantity necessary will, of course, depend upon the species of fish, some being able to survive in much lower concentrations of oxygen than others. It was noticed in some of the lakes sampled that when the oxygen content was low the

TABLE III.—*Condition of Water in Lake Silver (Control)*

Approximate Area = 52 Acres
Approximate Volume of Water = 204,000,000 Gallons

	April 1937	May 1937	June 1937	July 1937	Aug. 1937	Sept. 1937	Oct. 1937	Nov. 1937	Dec. 1937	Jan. 1938	Feb. 1938	March 1938	April 1938
Temp. Water, ° F.	—	—	—	88	86	82	74	66	66	64	65	78	75
Total Solids, P.P.M.	138	—	—	134	146	129	104	109	125	143	103	113	127
Organic Solids, P.P.M.	80	—	—	50	83	95	59	43	40	126	33	43	49
Inorganic Solids, P.P.M.	58	—	—	84	63	34	45	66	85	17	70	70	78
Suspended Solids, P.P.M.	1.5	—	—	1.8	6.2	3	3	2	1	0.4	0.6	0.3	0.3
pH	5.88	—	—	7.40	5.88	7.38	6.58	7.10	6.50	5.84	6.80	6.80	6.58
Dissolved Oxygen, P.P.M.	8.3	—	—	8.4	7.4	8.3	10.0	11.0	9.8	8.7	8.9	9.4	8.0
5-Day B.O.D., P.P.M.	0.33	—	—	2.4	0.5	1.1	0.4	1.0	0.5	1.0	0.8	2.1	0.0
Bacteria per c.c.													
20° C.	200	—	—	56	33	100	275	142	60	351	200	250	360
37° C.	0	—	—	17	117	190	234	160	52	194	137	250	230
Coliform Group	0	—	—	0	0	0	0	0	0	<1	0	0	0
Total Rainfall, in.	4.87	3.76	6.80	8.44	4.27	3.50	5.55	5.07	1.16	0.94	0.87	4.48	0.09

TABLE IV.—*Condition of Water in Pond at Florence Villa* *

Approximate Area = 3 Acres
Approximate Volume Water = 11,700,000 Gallons

	April 1937	May 1937	June 1937	July 1937	Aug. 1937	Sept. 1937	Oct. 1937	Nov. 1937	Dec. 1937	Jan. 1938	Feb. 1938	March 1938	April 1938
Temp. Water, ° F.	83	—	—	86	86	82	72	68	68	63	63	80	77
Total Solids, P.P.M.	352	—	—	305	355	372	308	330	340	345	310	364	414
Organic Solids, P.P.M.	340	—	—	127	266	157	85	189	221	97	56	88	114
Inorganic Solids, P.P.M.	12	—	—	178	89	215	223	141	109	248	254	276	300
Suspended Solids, P.P.M.	8	—	—	3	12	3	2	3	1	3	0.4	2	6
pH	7.00	—	—	7.17	7.48	7.27	6.07	5.40	6.59	7.20	6.60	6.20	6.74
Dissolved Oxygen, P.P.M.	0	—	—	1.6	1.8	5.6	4.3	11.9	9.3	9.3	8.5	8.7	8.1
5-Day B.O.D., P.P.M.	220	—	—	13.2	3.1	1.5	1.3	—	0	1.6	1.2	2.7	0.9
Bacteria per c.c.													
20° C.	320,000	—	—	3,600	119	75	166	280	216	230	175	90	200
37° C.	140,000	—	—	19,400	148	240	184	410	190	120	110	370	170
Coliform Group	670	—	—	1	0	0	<1	<1	<1	<1	0	<1	0
Total Rainfall, in.	4.87	3.76	6.80	8.44	4.27	3.50	5.55	5.07	1.16	0.94	0.87	4.48	0.09

* No canning plant effluent went into this pond after April, 1937.

fish would jump. It is probably safe to say that the dissolved oxygen in a game fish stream or lake should not for any length of time during the day be lower than 4 p.p.m. and that the average for 24 hours should always be over 6 p.p.m. In some instances in the lakes sampled the dissolved oxygen at the time of sampling was very near 6 p.p.m., and even

lower. This is particularly striking in the case of the lake at Dundee (Table II). In general, the dissolved oxygen decreased during the canning season.

In some instances dissolved oxygen was at the point of supersaturation, especially during the summer. This was probably due in part to the oxygenation brought about by the chlorophyll bearing plants and organisms which were abundant in these lakes. Although the lakes have no regular surface flow of water, they are fed by underground springs and during the summer receive huge amounts of water in surface run-off from the violent showers. The reoxygenation on the surface was probably at a minimum due to lack of turbulence and flow.

The 5-day B.O.D. values of the lakes showed less dramatic changes, although in general there seemed to be a tendency for an increase in B.O.D. during the canning season. This is clearly indicated in the lake at Dundee (Table II). The decrease in B.O.D. will also be noticed for the pond at Florence Villa which received no cannery effluent after April, 1937.

The solid content (total, inorganic, organic and suspended) seemed to vary considerably and showed no definite trend.

The bacterial count of the lake waters showed a tendency to increase during the canning season. This factor, was, however, somewhat confused by rainfall. After heavy rains (which come during the early summer and fall) the bacterial count increased, especially in those cases where the lakes received street washings as well as cannery effluents. *Escherichia coli* was identified on several occasions. The absence of the coliform group in the waters of Lake Silver was noteworthy.

To summarize: analyses of lake waters receiving cannery effluent, in some cases showed positive evidence of pollution and danger to fish life. Such evidence was not, however, clear-cut in every case.

Laboratory Experiments in the Treatment of Citrus-Cannery Effluents

The studies reported here were undertaken for the purpose of developing new or improved methods of disposal which could be applied to any citrus cannery in Florida. Methods already described, and some of which have been satisfactory in particular instances, are not applicable to all citrus canneries. A few canneries have found that none of the methods described can be used in their particular case, and for this reason attention was directed toward finding a satisfactory, practical and economical method which would be applicable to all citrus canneries.

Space will not permit a complete report of all the methods tried. Discussion must be limited to a summary of the results.

Chemical Precipitation.—The screened effluent was treated with lime, ferrous sulfate, alum, sodium aluminate, ferric chloride, bentonite and various combinations of these chemicals. Clear effluents could be obtained quite readily, but such effluents in general had a higher oxygen

consumed value than the untreated waste. Aeration of the chemically treated effluents (accomplished by spraying into the air) did not significantly improve their quality.

Activated Sludge.—A compact sludge, amounting to about one per cent by volume, was obtained, but the effluent showed little improvement over that before treatment.

Contact Filter and Sand Filter.—The filters clogged and gave considerable trouble. If given proper attention it is probable such filters would work, but the large space required, cost of construction and supervision while in operation seemed to discourage their use on a large scale.

Trickling Filter.—Such favorable results were obtained in the laboratory using this method of purification that it was decided to construct a small pilot plant at one of the canneries.

Pilot Plant—Trickling Filter

The experimental trickling filter was designed by Mr. George Catlett, Chief of the Division of Engineering of the Florida State Board of Health. The filter is shown in Fig. 2.

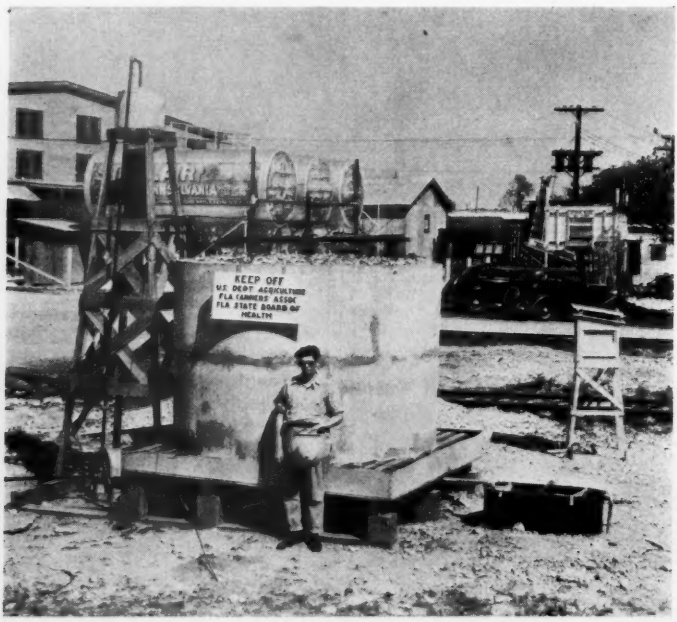

Fig. 2.—Experimental trickling filter for treatment of citrus-cannery effluent.

The filter consisted of a concrete shell 8 feet deep, resting on suitable underpinnings to permit ready drainage and free air circulation. As constructed, the area of the filter amounted to $\frac{1}{867}$ of an acre. Previous

laboratory experiments indicated that Ocala limestone would not be satisfactory as ballast because of extensive erosion. So-called Florida flint rock was obtained, this stone having approximately the following composition:

Silica (SiO_2)	93.1%
Calcium Carbonate	0.76
Magnesium Carbonate	0.31
Iron and Aluminum (Fe_2O_3 and Al_2O_3)	2.86

The stone ranged in size from about one inch to three inches; the larger pieces being packed at the bottom of the filter. The stones held up well during the experiments, although there was some erosion.

Referring to Fig. 2, at the left of the filter is a tower upon which is mounted the dosing tank having a capacity of 8.86 gallons. This tank, of concrete and coated internally with an asphalt paint, was provided with a bell and siphon arrangement so that dosing would be automatic. Orifices of suitable size were placed in the pipe leading to the dosing tank and the pipe from the dosing tank to the distributor on the filter. By regulating the size of these orifices, the time of dosing and resting of the filter could be accurately controlled.

The distributor consisted of two pipes with perforations of suitable size so that the entire bed would be uniformly dosed. It was made to rotate (by means of a motor) at about 12 R.P.M. The distribution arm was raised above the bed so that there would be some splashing of the material as it gushed from the arms (Fig. 3).

The biological film on the ballast was built-up by adding dry skim milk powder and cow dung. Later, orange and grapefruit juices were sprinkled on the bed. In this manner a fairly satisfactory formation was obtained in two or three weeks.

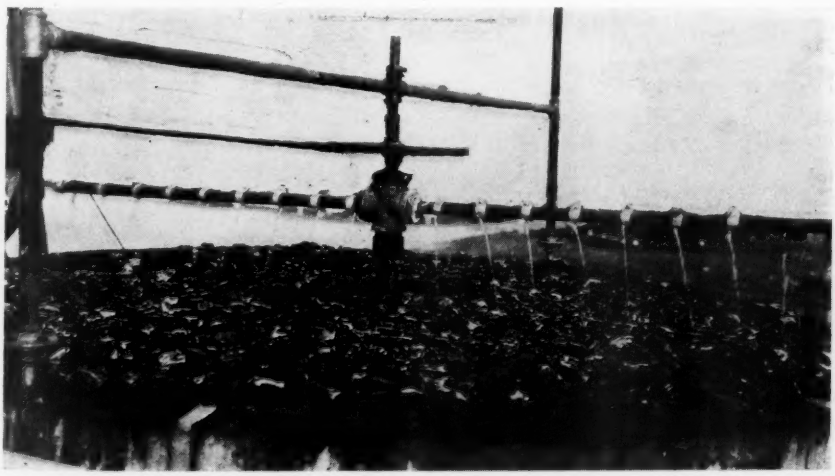

FIG. 3.—Rotating distributor for trickling filter.

The filter was in operation approximately 10 hours a day with the exception of Saturdays and Sundays.

After the filter had been in operation for about 60 days, the cannery closed for about a month. This rest-period had no serious effect in that the efficiency of the filter built up rapidly when it was started again.

Hourly samples were taken of the filter influent and effluent and of the settling-tank effluent. Hourly temperature readings were also made of the influent and effluent of the filter. Hourly morning samples were composited for analysis; hourly afternoon samples were also composited thus giving the functioning of the filter in the morning as compared with the afternoon. Samples were kept on ice until ready for analysis; in no case was analysis made more than five hours after samples were taken.

Effluent from the filter was allowed to flow into a settling tank (Fig. 4) where it was retained for about two hours. This permitted

FIG. 4.—Secondary settling tank.

some settling of the material sloughing from the filter, and that naturally present in the waste. Settling was not, however, entirely complete and the effluent from the settling tank always contained finely suspended matter. Longer retention time would not remedy this, because all the settleable material was found to settle within two hours.

It was necessary to frequently clean the sludge from the settling tank, since this sludge became septic (especially during warm weather) gassed, created foul odors and floated to the top of the tank where it was discharged with the effluent.

An analysis of the sludge is given in Table V. If dried, the sludge would have a value as a fertilizer, and is comparable in composition to sludge obtained from domestic sewage.

TABLE V.—*Analysis of Sludge from Settling Tank in Treatment of Citrus Cannery Effluent*

Fresh Sludge	
Sp. Gr. at 20° C./20° C.	1.001
Water	99.89%
Organic Matter	0.06
Inorganic Matter	0.05
Dry Sludge	
Crude Fat (ether extract)	7.42%
Total Nitrogen, as Ammonia	4.90
Ash	31.90
Phosphates (P_2O_5)	2.37

In practice, it would be necessary to oil the surface of the settling tank to control mosquitoes.

Operation of Filter and Discussion of Results.—Before being pumped to the filter, the canning plant effluent was passed through a 40 mesh screen with openings of approximately 0.015 inches (Fig. 5).

A summary of the data for three dosing rate equivalents is given in Table VI. During the periods indicated, the filter was dosed for about three minutes and rested three minutes. Although reductions in 5-day B.O.D. were not as great as some authorities might expect, it is quite likely that the lakes would be able to take care of an effluent having a 5-day B.O.D. of about 100 p.p.m. Such an effluent would be obtained with a dosing rate of slightly more than 1.5 million gallons per acre per day, if the canning plant effluent had a 5-day B.O.D. of about 900 p.p.m. It was found that a rate of 1.5 million gallons per acre per day gave the best results. At rates greater than this, the efficiency of the filter was impaired.

Reaction of the Influent and Effluent.—Normally the pH of the influent to the filter was about 6.3, while the effluent had a pH of approximately 7.3. The effluent from the settling tank also had a pH of nearly the same as the filter effluent. If, however, the settling tank became septic, its effluent became more acid than that of the filter.

Temperature of Influent and Effluent.—The filter influent always had a higher temperature than the effluent, the difference between the two amounting to 20° F. or more. The comparative coolness of the effluent was, of course, due to evaporation.

It was found the cooler the atmospheric temperature, the less efficient the purification. This is probably due to the inability of the or-

ganisms on the ballast to grow and function as efficiently at low temperatures as at higher temperatures (Fig. 6).

Effect of Rest Periods upon Efficiency of Filter.—The filter was normally in operation about 10 hours a day and rested overnight, Saturday afternoons and Sundays. From 101 daily observations, it was found that greater purification was obtained in the afternoons 50.4 per cent of

FIG. 5.—Rotary screen for screening citrus-cannery effluent prior to passing through trickling filter.

the time; greater purification in the mornings 39.6 per cent of the time, while 10 per cent of the time showed equal purification in the afternoon and morning. It should also be mentioned that there was no consistent difference between the strength of the canning plant effluent in the morning and afternoon. The data would indicate that resting overnight and week-ends probably resulted in some drying of the film with a resulting

TABLE VI.—*Summary of Data for Trickling Filter. Dosing, Intermittent*

Operating Period	12/5 to 1/9	1/18 to 3/7	4/10 to 4/25
Equiv. Dosing Rate, M.G.P.A.P.D.	2.16	1.38	1.56
Mean Air Temp. ° F.	63.6°	68.9°	68.6°
Temp. Infl., ° F.	84.3°	87.4°	89.8°
Temp. Effl., ° F.	64.2°	65.5°	70.1°
Oxygen-Consumed Value (p.p.m.)			
Infl.	762	755	1021
Effl.	309	113	184
Settling Tank	279	99	131
5-Day B.O.D. (p.p.m.)			
Infl.	641	633	876
Effl.	302	68	108
Settling Tank	291	79	101
pH Value			
Infl.	6.49	6.25	6.48
Effl.	7.04	7.33	7.42
Settling Tank	7.02	7.27	7.33
Overall Reduction in Oxygen-Consumed Value, %	63.4	86.8	87.1
Overall Reduction in 5-Day B.O.D., %	54.6	87.5	88.4

decrease in efficiency. From a practical standpoint, however, this decrease would be of relatively little importance.

Relation between B.O.D. and Oxygen Consumed Value.—In the citrus cannery effluents studied, there was no consistant relationship between the oxygen consumed value and 5-day B.O.D.

Effect of Adding Nitrogenous Nutrients to Filter Influent.—Since the nitrogen content of the influent was low (10 p.p.m.) it was thought that the efficiency of the filter could be increased by the addition of nitrogenous nutrients. Ten parts per million of nitrogen were added as ammonium hydroxide, ammonium carbonate, ammonium nitrate and dried blood albumen.* The results are summarized in Table VII. From the data it will be seen that the addition of blood albumen increased the efficiency of the filter. However, material cost to obtain this increased efficiency would amount to about $11.00 per 100,000 gallons of cannery effluent.

Effect of Chlorination.—It was found that the chlorine demand of the particular effluent being studied ranged from 250 to 400 p.p.m. Obviously, it would be economically impossible to satisfy this demand. Experiments were, however, conducted to learn what effect partial satisfaction of the demand would have on the subsequent purification of the waste. The canning plant effluent was dosed with 50 p.p.m., the chlorinated waste then being passed through the trickling filter. It

* This should not be confused with dried, whole blood which contains considerable insoluble matter. The blood albumen used was dried haemoglobin (with, of course, a small amount of plasma) and contains little insoluble matter when fresh. Briefly, it is prepared by centrifuging citrated whole beef blood, thus separating the plasma from the haemoglobin. The haemoglobin is then spray-dried.

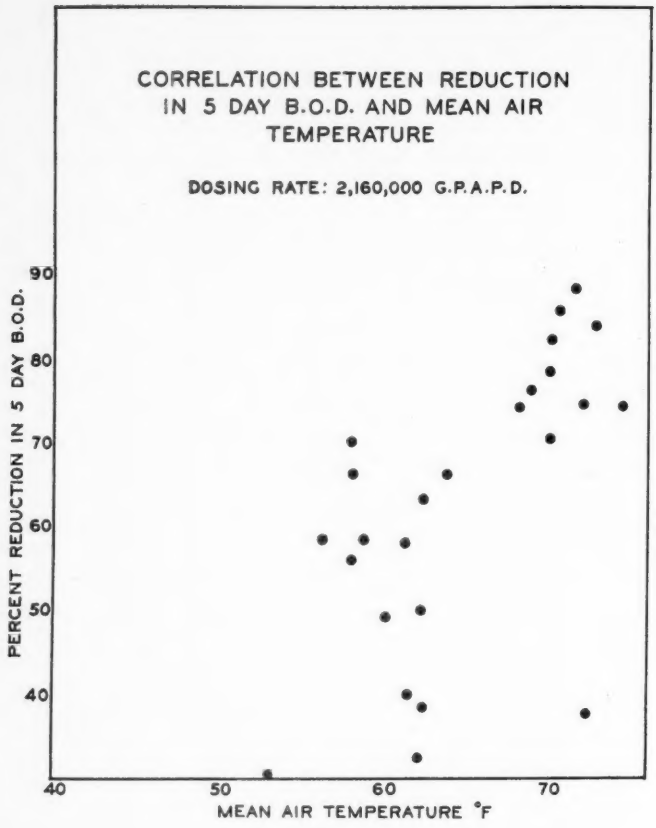

FIG. 6.

TABLE VII.—*Effect of Adding Nitrogenous Nutrients to Citrus Cannery Effluent and its Ultimate Purification by Trickling Filtration*

(Dosing rate, 2,160,000 gallons per acre per day)

(10 p.p.m. of nitrogen added)

Nutrient	5-Day B.O.D.		Pounds B.O.D. Removed per 100 Cu. Ft. of Filter per Day
	Influent, P.P.M.	Settling Tank, P.P.M.	
Control	760	140	4.24
Inorganic Ammonium Salts	771	174	4.13
Blood Albumen	934	165	5.36

should be pointed out that the addition of even 50 p.p.m. would prove a costly undertaking in practice.

Partial satisfaction may have an effect upon ultimate purification as shown in Table VIII, but the degree of purification attained would not warrant the additional expense.

TABLE VIII.—*Effect of Partially Satisfying the Chlorine Demand of Citrus-Cannery Effluent and Subsequent Treatment with a Trickling Filter*

(Dosing Rate: 2,160,000 gallons per acre per day)

(50 p.p.m. chlorine added)

	5-Day B.O.D.		Pounds B.O.D. Removed per 100 Cu. Ft. of Filter per Day
	Influent, P.P.M.	Settling Tank, P.P.M.	
Control	760	140	4.24
50 P.P.M. Chlorine	822	133	4.67

The data obtained from recirculating citrus cannery effluent are given in Table IX. Each experiment represents data obtained when the filter had reached equilibrium. This was taken to be when the oxygen consumed value and 5-day B.O.D. of the filter effluent were constant, or nearly so. Recirculation at the rate indicated, and under the conditions of the experiment, failed to have an effect upon ultimate purification of citrus cannery effluent.

TABLE IX.—*Effect of Recirculation on Purification of Citrus-Cannery Effluent. Filter Dosed Intermittently*

(Rate of feed plant effluent: 1,560,000 gallons per acre per day)

5-Day B.O.D.		Pounds B.O.D. Removed per 100 Cu. Ft. of Filter per Day	
Plant Effluent, P.P.M.	Settling-Tank Effluent, P.P.M.		
876	101	3.84	Control, no recirculation.
704	10	3.44	Filter influent consisted of one part plant effluent plus one part of filter effluent.

Size of Trickling-Filter Needed.—Our experiments indicated that citrus cannery effluents could be satisfactorily treated by means of a properly operated trickling filter of adequate size. From a practical standpoint, the size of such a filter becomes of primary importance. The size will depend upon the quantity of effluent to be treated, and the B.O.D. of this material. These factors will vary with nearly every citrus cannery. Although it is not possible to accurately define the size of filter needed in every instance, a very close approximation may be obtained from the formula:

$$\frac{\dfrac{\text{pounds of effluent to be treated}}{1{,}000{,}000}\ (\text{B.O.D. to be removed})}{0.246}$$

In the above formula 0.246 is a constant obtained by multiplying the depth of the filter (6 feet) by the average pounds of B.O.D. removed per

cubic foot of filter. From the data obtained in our experimental work, and which extended over a period of seven months, the average pounds of B.O.D. removed per cubic foot of filter was found to be 0.041. This figure represents the value for reasonable or normal operation.

As an example of the use of the above formula, suppose a plant is packing 4000 cases of No. 2's per 10-hour day.* Such a plant would have an effluent of about 226,000 gallons, or 1,882,580 pounds per 10-hour day. In the case of 24 hours' operation (and this fact must be taken into consideration) there would be 542,400 gallons, or 4,518,192 pounds. Again, assume this effluent to have a maximum B.O.D. of 800 p.p.m., and that this will be reduced to 100 p.p.m. by the treatment. Substituting these values:

$$\frac{\frac{4{,}518{,}192}{1{,}000{,}000}\ (700)}{0.246} = 12{,}855 \text{ sq. ft. surface area.}$$

It should be pointed out that the size of the filter must be calculated as though the canning plant were running 24 hours a day.

Cost of Disposal Plant.—This question cannot, of course, be definitely answered. In Florida, the cost would be high because of the high price of flint rock used for ballast. This material costs about $3.50 a cubic yard delivered. At this price ballast for packing the filter cited above would amount to about $10,000. To this figure must be added construction cost.

A cheaper material might be found in the form of broken tile, concrete pipes or cypress blocks of small size. Lime rock could be obtained cheaply, but it would have to be replaced each season. Ballast material costing not more than $1.00 per cubic yard delivered would have to be used.

The contention that the price of ballast is high may be ridiculed by some sanitary engineers. It must be remembered, however, that when the citrus canner invests in a disposal plant, the only way he can get his money back is from the consumer, *i.e.* by increasing the price of the canned product. The consumer might very well rebel at this.

Summary

It was found that the effluents from citrus canneries amounted to about 56 gallons per case of No. 2's and had a 5-day B.O.D. varying from 100 to 2000 p.p.m. Effluents from plants processing juice had a lower B.O.D. than those processing sections, or juice and sections. The chemical composition of the effluents consisted chiefly of inorganic salts and organic solids (organic acids, pectin and sugar). Of the total solids, from 2 to 94 per cent consisted of sugars, and from 0.04 to 0.5 per cent acid as citric. The nitrogen content was very low, amounting to only about 10 p.p.m.

* This would be an average size plant.

Some lakes of insufficient area for proper dilution and into which citrus cannery effluents were emptied, showed positive evidence of pollution and danger to fish life.

Purification of effluents was attempted by chemical precipitation, activated sludge, contact filter, sand filter and a trickling filter.

Trickling filtration, using an experimental unit, was found the most satisfactory and from the data obtained it was found:

Trickling filtration offered the most promising solution for the disposition of citrus-cannery effluents in those cases where flooding of isolated tracts of land or emptying into tidewater rivers or large bodies of water is impractical.

Addition to the cannery effluent of nitrogenous nutrients in the form of blood albumen resulted in an increase in filter efficiency of the filter, but material cost of such practice would be too high.

Chlorination of the cannery effluent was too expensive. Partial satisfaction of the chlorine demand slightly increased the efficiency of the filter, but cost would be excessive.

Under the conditions of the experiments, recirculation had no effect upon the efficiency of the filter.

The higher the mean air temperature the greater the efficiency of the filter.

Construction costs of a trickling filter in Florida would be high if Florida flint rock were used as set forth in these experiments.

Acknowledgment

We express our appreciation to the Florida Canners' Association without whose financial assistance the work could not have been undertaken; to Mr. George F. Catlett, in Charge of the Engineering Division of the Florida State Board of Health for the plan of the filter construction; to the Seaboard Airline Railroad for the loan of the land upon which the disposal plant was erected; to Mr. J. R. Hoy of Wallace and Tiernan for the use of their chlorinator; to Mr. W. McLean Bingley of the Dorr Co. for their experimental flocculator; to the Pacific Flush Tank Co. for the bell and siphon used; and to the Bordo Products Co. of Winter Haven, Fla. for their many courtesies.

Operators' Reports and Suggestions

W. D. Hatfield

249 Linden Place, Decatur, Ill.

OPERATION OF THE MASSILLON, OHIO, SEWAGE TREATMENT PLANT FOR THE YEAR 1939

By R. F. Snyder

Superintendent

This plant was placed in operation in October, 1939. It was designed for a population of 36,000 or an average flow of 5.2 m.g.d. (Fig. 1).

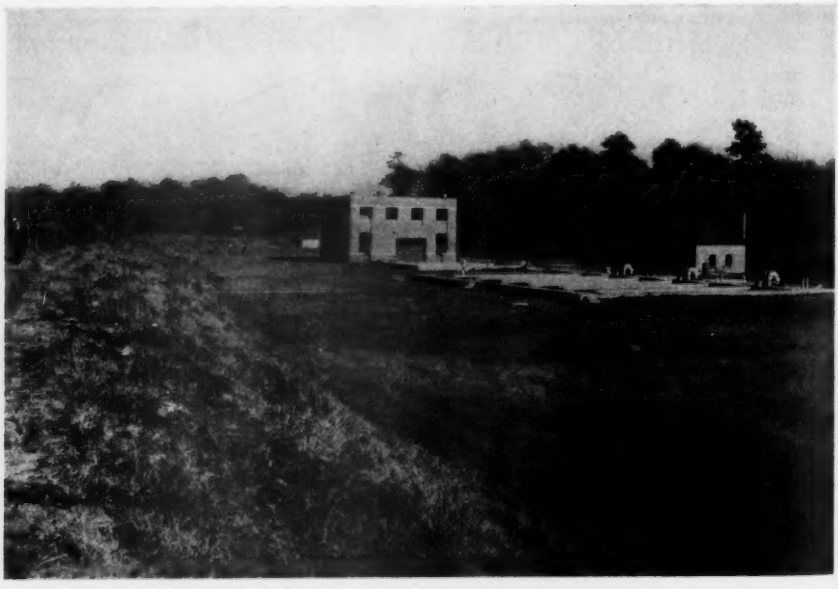

Fig. 1.—Massillon Sewage Treatment Works. Bar grate and by-pass chamber in the background. Main building housing pumps, chemical feed and flash mixing equipment, venturi meter, office, laboratory and garage. Flocculation tank. Primary settling tanks. Area to right of settling tanks is for secondary treatment units when needed.

The plant was designed for primary treatment only, and for the use of chemicals for seasonal operation when the river is low. The works consist of manually cleaned bar grates with one inch openings, flash mixer, flocculator, settling tanks, digesters and sludge drying beds, both covered and open (Fig. 2).

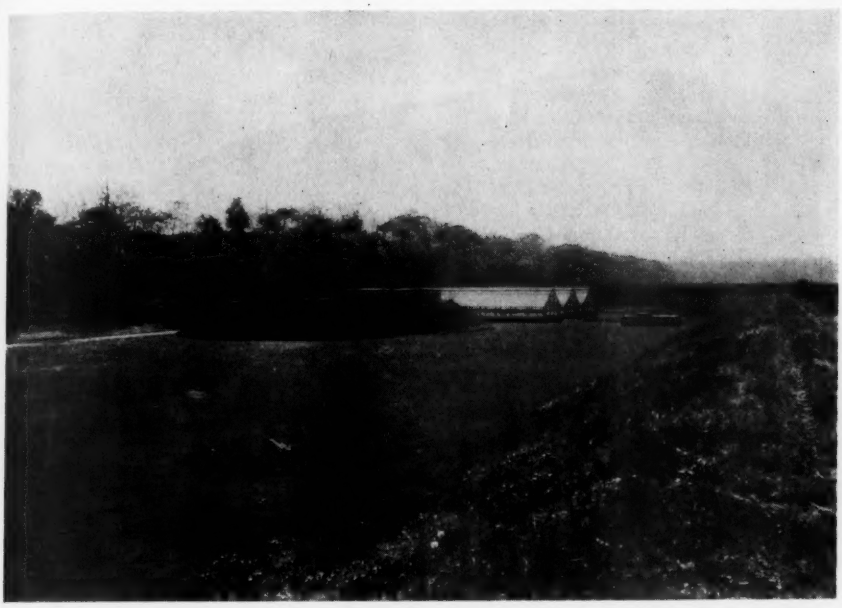

FIG. 2.—Sludge digestion tanks. Covered sludge drying beds. In back of covered beds are open drying beds of the same area. Low concrete structure to right is the automatic storm water pumping station in use when river is 5 ft. or more above normal stage.

General Plant Operation.—A complete summary of the operation of the plant is contained in Table I.

Cost data are given in Table II.

Settleable solids determinations are made at 2-hour intervals daily due to the unusual precipitation of the iron in the sewage at irregular intervals day and night and this gives us a good indication of our expected solids removal from the settling tanks. The efficiency of settleable solid removal was obtained by using the average of the monthly averages. It has been quite interesting to note from day to day that the effluent from our settling tanks seldom contains more than a trace of settleable solids and then it is usually iron that has precipitated out after the Imhoff cone has been filled for about an hour.

B.O.D. results given in the report were obtained by the Winkler method using sodium bicarbonate dilution water. When the plant was first started the permanganate (Rideal-Stewart) modification was used but the slight difference in results did not justify the time or chemicals used with this method.

Total iron was determined by colorimetric methods as outlined in "Standard Methods for Water Analysis." Dilutions were made when the iron content of the sewage was high.

The acidity of the acid wastes was determined by making a dilution of the waste and then adding an excess of 0.2 N sodium hydroxide to the diluted sample in excess of that necessary to neutralize the acid and

TABLE I.—*Summary of Operation Records for Year, 1939*

Operation	Daily Averages
Sewage Flow	2.71 m.g.d.
Screenings Removed	0.054 cu. yd.
Fresh Solids Pumped to Digester (4.9% solids, 71.05% volatile)	12,000 gal.
Digested Sludge Removed from Digester (5.12% solids, 50.2% volatile)	4,360 gal.
Sludge Removed from Drying Beds	3.72 cu. yd.
Gas Production	41,272 cu. ft.
Analytical	
Total Solids	
Raw	1,352 p.p.m.
Effluent	1,133 p.p.m.
Suspended Solids	
Raw	239 p.p.m.
Effluent	73 p.p.m.
5-Day B.O.D.	
Raw	131 p.p.m.
Effluent	68 p.p.m.
pH	
Raw	6.4
Effluent	6.5
Total Iron as Fe	
Raw	104 p.p.m.
Effluent	90 p.p.m.
Ferrous Iron as $FeSO_4$	
Raw	97 p.p.m.
Effluent	80 p.p.m.

TABLE II

Operation Cost—Sewage Disposal Department

Capital Charges	$31,091.37
Sewage Treatment Works	14,557.44
Sewer Rental Collection Office	3,045.18
Maintenance of San. Sewer System	2,290.88
W.P.A. Projects	1,978.88
Refunds on Over Charges	49.40
Total	$53,013.15
Cash Sludge Sales	305.95
Net Operating Cost of Department	$52,707.20

Operation Cost—Sewage Treatment Works, 1939

Payroll	$10,828.17
Power and Light	1,973.95
Equipment and Supplies	1,194.60
Stationery, Printing and Postage	10.00
Incidentals (Telephone etc.)	173.78
Employees Retirement Fund	340.75
Chemicals	36.19
Total Operation Cost	$14,557.44
Net Operating Cost	14,557.44
	305.95(Sludge Sales)
	=$14,251.49

precipitate the iron. The excess hydroxide was determined by titration with 0.1 N sulfuric acid and the combined acid and iron content calculated and expressed in terms of H_2SO_4. The iron in the sample was determined by oxidizing the ferrous to ferric iron and then precipitating it with ammonium hydroxide. The precipitate was ignited and weighed as ferric oxide and converted to its equivalent weight as ferrous sulfate and this in turn to its equivalent weight as H_2SO_4. The acidity was then calculated from the difference between this result and the combined weight of the acid and iron expressed as H_2SO_4. From this result the per cent acid was determined.

The principal results of the plant operation and treatment obtained are given below.

Daily average flow on the basis of actual time the plant was in operation	2.71 m.g.d.
Dry solids removed as sludge in the settling tanks and treated in the digesters	849 tons
Efficiency of removal of settleable solids in the settling tanks	99.6 %
Per cent removal of suspended solids by the settling tanks (This is the average of the monthly averages. If based on the average of the years analysis it would be 69.2%.)	66.4%
Average removal of 5-day biochemical oxygen demand	47.5%
Daily average gas production	41,000 cu. ft.
Sludge removed from drying beds	1,280 cu. yd.
Total iron as Fe in sewage treated for the year	407 tons
Total iron as $FeSO_4$ (ferrous sulfate) in sewage treated for the year	1,107 tons
Kilowatts of power used	134,340
Average cost per kilowatt	.0147

During the past year all units have operated properly and efficiently and in general the plant has produced a degree of treatment at all times which is above the average for this type of plant as well as meeting all of the requirements of the State Department of Health for the treatment of sewage.

As stated above we have had a suspended solids removal of 66.4 per cent based on the average of the monthly averages. On the basis of the year's average analysis, removal of suspended solids has equaled 69.2 per cent.

The sludge digestion tanks have functioned properly and a well digested and stabilized sludge has been obtained at all times. The gas production has been high but this is another indication that the digestion process is proceeding favorably.

The dried sludge from the digestion process has been disposed of by selling it to farmers as well as to home owners and others for use as fertilizer for crops, gardens, flower beds, shrubbery and for top dressing on lawns. During the spring and early summer we not only sold our entire output but also the sludge that was on the stock pile from the previous fall and winter. We now have sludge on the stock pile from last fall when the demand was low but I believe we will have ready sale for all of this again this spring.

The cash sludge sales for 1939 amounted to $305.95 which is an in-

crease of 115 per cent above last year. In addition to this, coal was supplied to the incinerator and payment for it was taken in sludge. Fuel was delivered to the incinerator in an amount equal to $79.21 and payment for this was taken in sludge at such times when we had an excess on hand for which we had no demand. Not only did the city receive a direct benefit in fuel for the incinerator at no cost to the city but also we had an additional direct savings in labor cost for the removal of this sludge from the beds. For each $5.00 sale of sludge directly from the beds we likewise save about $3.50 in labor. Therefore we not only have a small return in cash from the sale of sludge but also a direct savings in plant operation costs.

In addition to this, sludge was furnished free of charge to the park department, the city hospital, both the main and west side libraries, and to the garden section of the Woman's Club for civic improvements in connection with the clean-up drive and public beautification of the city for which Massillon won first place.

With the increasing demand for sludge during the past year there has also been a strong demand for it in a pulverized condition. Other sewage plants have pulverized it and thereby greatly increased their sales to the point where it was more profitable to sell sludge in the pulverized state. In December it was found that sufficient sludge has been sold to offset the cost of a pulverizer and necessary accessories and at this time a Royer sludge pulverizer was purchased. Electric outlets will be located so that the portable unit can be operated at any desired point around the sludge beds and stock piles. The electric installation however has not been made as yet due to the depth of frost in the ground which has prevented our laying the underground feeder cable to points from which the pulverizer will be operated. As soon as weather conditions permit this installation will be made.

Changes made in our bar grate openings in the fall of 1938 have proven to be successful and the operation of the raw sewage pumps and check valves has been greatly improved.

Due to the settlement of the ground fill around the sludge digestion tanks the four-inch water line which supplies the control chamber broke during the first part of November and had to be dug up and repaired. This repair work was done by our own men at the plant. All repairs, maintenance and installation work in the past have been done by ourselves without the aid of outside help.

Industrial Waste Problem.—At the beginning of last year it was found that pickling liquor wastes were coming into the plant in such strength that they were beginning to disintegrate the metal of the No. 3 raw sewage pump impeller. This pump carries most of the load because its capacity is about equal to the sewage flow now entering the plant.

Samples of this acid waste were obtained and analysis in the laboratory indicated that they contained approximately 3 per cent free acid. These samples were likewise high in dissolved iron in the form of ferrous sulfate.

On November 15th it was necessary to shut down the No. 3 raw sewage pump because the impeller of this pump was so badly eaten up that it was not safe to operate any longer (Fig. 3). New pump parts were immediately ordered and the replacement parts were made of acid resisting iron. These new parts were obtained at a cost of approximately $350.00.

FIG. 3.—Raw sewage pump impeller eaten by acid industrial waters. This pump was in operation only part time of the first two years the plant was in operation.

Plant Improvements.—In order that complete pumping records would be available and that the Venturi meter would be more efficient for proper control of the plant the new set of differential gears that were purchased in December of 1938 were installed in the meter recording and registering unit. This change was not made until February, 1939, when the supply of old meter charts was used up. Through this change a complete pumping record is available at all times and the necessity of frequent meter adjustment is eliminated.

Plant improvements and additions have also been done under W.P.A. work relief projects. At the time the new stadium project was started last spring a request was made for the evergreens and shrubbery that had to be removed for this project. W.P.A. labor was used to remove and replant the trees and shrubbery and in this way we were able to get a start in improving the appearances of the grounds around the plant. In addition to this the operating personnel of the plant has donated both shrubbery and flowers to add to the plant appearance.

During the past year the solids loading to the digesters had increased to the point where it was necessary to construct additional sludge drying beds to properly handle the increased amount of digested sludge that had to be dried. Three new units of four beds each were built with W.P.A. labor. These units are exact duplicates of the three existing units with the exception that glass covers were not provided at this time (Fig. 4).

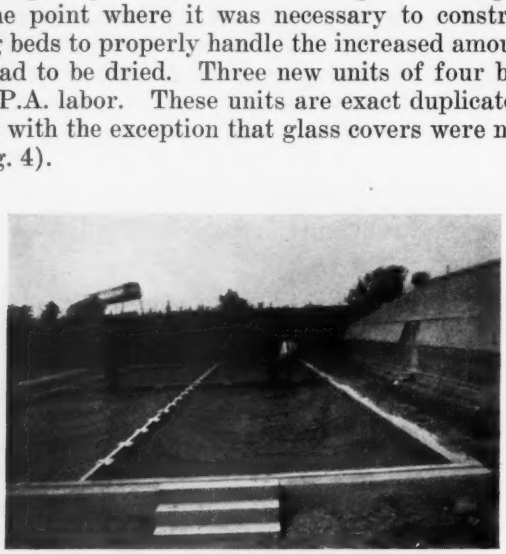

FIG. 4.—Open drying beds. Flood protection levee in background.

For the present time the open beds will provide the necessary drying area needed and since the cost of the glass covers is quite high it is considered advisable to eliminate them until a later date. The beds as constructed furnished an ideal project for relief labor and the cost to the city was very low for the benefits obtained. The fabrication and erection of the glass covers is all specialized work and would provide little if any relief work for local men (Fig. 5).

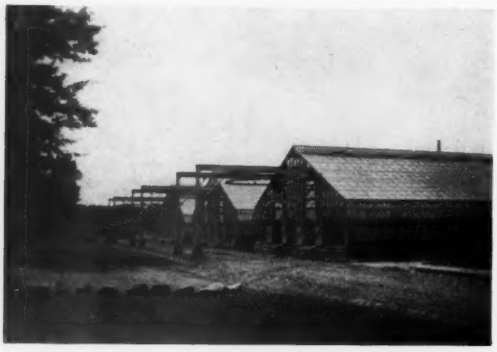

FIG. 5.—Covered sludge drying beds.

Experimental Work.—Last June the Secretary of the Ohio Conference on Sewage Treatment, which is called by and meets with the State Department of Health once each year, asked that special experimental

work be started on the flocculation of sewage without the use of additional chemicals, under conditions as they exist here. This work was carried on for six weeks and a written report was submitted and read at the conference which was held in Toledo on October 5th and 6th, 1939. This is the only time that the chemical treatment units have been in continuous operation. Through proper laboratory control we have been able to obtain a high degree of treatment at all times without the operation of these units which has resulted in a saving of chemicals which, had it been necessary to use them, would have cost in excess of $2000.

Operating Personnel.—At the beginning of 1939 the plant operating personnel consisted of: a superintendent, chief operator, two shift operators and a relief operator.

In April it was necessary to add one laborer to help handle sludge removal from the drying beds, general plant maintenance and taking care of the lawns and grounds around the plant. On October 16th he was taken sick and had to quit because of his physical condition. He was replaced in November at the time the break in the water line occurred and is still on the plant personnel. Prior to last April all outside work was done by W.P.A. labor as a part of the landscaping and seeding project but since then it has become a direct part of the plant operation and maintenance work.

Examinations for certification by the State Department of Health of sewage works operators was held in Cleveland on November 3, 1939 for this district. The examinations were taken and certificates of class D grade were obtained by all operators. The superintendent was rated with a class A certificate.

Safety Record.—During the past year no accidents of any kind occurred to the operating personnel at the plant that required medical attention or loss of time. Minor cuts and bruises were given immediate first aid attention at all times and the supplies of our first aid cabinet have been properly and promptly replaced as needed. At the present time we have one man who holds a certificate issued by the American Red Cross qualifying him as having passed the examination for first aid work.

Public Interest in Sewage Treatment.—During the past year 702 registered visitors have inspected the plant. The visitors were not only from Massillon and Ohio but from eleven other states as well. These visitors have come from New York to California and from Michigan to Florida.

We had requests from eleven different groups to inspect the plant and are glad to have the opportunity to conduct these inspection trips at all times. These groups include the Junior Chamber of Commerce, Ohio Water Service Employees, the Northeastern Ohio Conference on Sewage Treatment representing fifteen sewage plants in the state, the Canton Regional Society of Professional Engineers and Surveyors, Scout Troops, science classes of both Washington High and Jackson Township High Schools, teachers from Greensburg Schools and the Vocational Apprentice Plumbers classes from Canton.

The sewage disposal division has received some unfair and at times grossly inaccurate criticism concerning not only the operation of the plant and what is actually being accomplished here in the treatment of the sewage but also in the rental assessments made and the purpose for which it is being used. The average citizen of Massillon has little or no conception of what is required in the treatment of sewage. Those who have criticised the plant and its operation are the ones who have obtained their information from sources other than the plant or persons who are not properly informed of the work accomplished here. Those who have visited the plant and learned of its operation have realized and admitted that in their opinions the sewer rental assessment is a reasonable and justified charge for what is being done in the proper treatment and disposal of the sewage of Massillon.

Since the sewage works has been in operation I have been asked to give talks concerning the features of the plant and its operation as well as the general subject of proper sewage disposal for cities and communities and a complete explanation of the sewer rental charges and the purposes for which it is used. I consider such opportunities as being the best means of bringing the subject of sewage treatment and disposal to the attention of the citizens of Massillon.

Proper and correct education of the people of the city to the value of complete control of such health hazards should not be overlooked and I welcome the opportunity at all times to speak upon or discuss the value of adequate sewage disposal for the city of Massillon and the operation of the sewage treatment works.

SALIENT FEATURES OF THE SEWAGE TREATMENT WORKS AT LIMA, OHIO

By E. E. Smith

General Superintendent

The plant was built in 1931 with a design population of 70,000, equivalent to 7 m.g.d. The present flows average 4 to 4.5 m.g.d. Flows are measured by a Venturi meter located between the primary tank and the aerators. Flows above maximum capacity (14 m.g.d.) are automatically by-passed. Controlled gates permit the by-passing of all sewage to the river.

The plant consists of a screen chamber, Dorr Detritor, two Dorr clarifiers, four aeration tanks, two Dorr sludge tanks, two circular Dorr covered concrete sludge digestion tanks and ten covered sludge drying beds.

The screen chamber consists of an enclosure 5 ft. by 11.5 ft., housing mechanically raked Dorr type bar screens with ¾ in. clear openings and a screening incinerator.

LIMA SEWAGE TREATMENT WORKS.—*Summary of Operation Results, Annual Means*

Year	Prec. In.	Flow, M.G.D.	Aeration			Suspended Solids					B.O.D.					Dissolved Oxygen		Digested Sludge			Sludge pH		Digester Gas		Operation Cost		Operation Period
			C.F. Air / Gal. Sew.	R. S., %	Solids Aeration	Sludge Index	Crude, P.P.M.	Sett., P.P.M.	Final, P.P.M.	Prim. Rem., %	Overall Rem., %	Crude, P.P.M.	Sett., P.P.M.	Final, P.P.M.	Prim. Rem., %	Overall Rem., %	Above Plant	Below Plant	Wet, Cu. Yd.	% Sol.	% Fix.	Raw	Dig.	Daily Production	Daily Waste	Total	Per M.G.	
1933	38	5.55	1.48	20	2920	1.44	191	99	24	48	89	175	135	38	23	80	7.1	4.1	5203	7	54	6.8	7.7	41,600	21,100	25,784	13.12	8 Mo. Act. 4 Mo. Double Sett.
1934	24	4.86	1.85	47	3200	0.91	210	105	49	50	76	232	176	55	24	76	6.4	3.3	6134	7	53	6.9	7.7	48,300	24,400	30,764	17.35	7 Mo. Act. 4 Mo. Double, 1 Single Sett.
1935	35	4.68	0.93	19	3090	1.69	193	97	10	50	95	208	160	13	23	94	5.5	2.8	4758	8	52	6.6	7.3	43,400	16,700	27,879	16.32	12 Mo. Act. Comp. 12 Months
1936	26	4.81	1.27	25	1840	1.24	203	99	13	51	94	211	148	16	30	92	4.6	2.1	3170	9	56	6.4	7.4	46,600	25,900	25,020	14.35	12 Mo. Act. Comp. 12 Months
1937	46	4.95	1.25	26	2300	1.29	156	79	12	49	77	133	100	14	25	90	6.5	2.5	3380	9	59	6.4	7.3	35,700	20,900	26,963	14.80	8 Mo. Act. 4 Mo. Single Sett.
1938	34	4.37	1.29	37	1997	1.27	167	76	20	54	88	165	110	26	33	84	6.5	2.8	3270	7	51	6.3	7.3	43,070	19,800	26,100	16.32	12 Mo. Act. 3 Mo. Partial Sett.
1939	35	5.93	1.04	28	1712	1.15	185	89	23	51	86	153	103	14	32	82	6.2	1.7	4252	5	51	6.3	7.4	47,700	17,800	24,550	11.72	12 Mo. Act. 4 Mo. Partial Sett.
1933 / 1939	34	5.03	1.30	29	2437	1.28	186	92	22	50	86	182	133	25	27	85	6.1	2.8	4310	7	54	6.5	7.4	43,770	20,940	26,723	14.56	7-yr. Over-all Means, Incl. Partial Trt.

The Dorr Detritor is a tank 20 ft. square with rounded corners having a capacity of 14 m.g.d. and a detention period of 0.6 min. Grit passes to grit channel, is agitated, washed and removed by Dorr rakes.

Sedimentation of the sewage is accomplished in two Dorr clarifiers, each having a capacity of 466,000 gal. and a detention period of 1.6 hr. with a 7 m.g.d. flow.

The four aeration tanks are of the return flow type with two channels each having a capacity of 405,000 gallons. The detention period for 8.75 m.g.d. (7 m.g.d.—25 per cent return sludge) is 4.5 hr.

The two Dorr final settling tanks have a total capacity of 712,000 gal. and a detention period of 1.96 hr. with a flow of 8.75 m.g.d. The sludge is drawn by gravity to the return sludge sump in the main building.

The two digestion tanks have a total capacity of 250,000 cu. ft. or 3.6 cu. ft./cap. based on a population of 70,000.

The covered sludge beds are each 20 ft. by 174 ft.

The effluent flows into the Ottawa River.

The following tabulation shows the average annual operation records and analyses from 1933 through 1939.

UNDER YOUR GLASS TABLE TOP

By W. D. Hatfield

Superintendent, Decatur, Ill., Sanitary District

Every superintendent or plant operator has numerous calculations to do, conversion factors to use and charts to refer to. Those which are used daily are easily retained in the mind but those used only occasionally must usually be looked up in references, books, tables, etc. Each man naturally accumulates certain data which he uses and although each plant will need certain data peculiar to itself, in general the data will be about the same. It may be of interest to list the data which have accumulated under my glass top.

1. A discharge curve of the Sangamon River over the Water Works Dam at Decatur.
2. A discharge curve (approx.) of the river at the sewage treatment plant according to river elevations.
3. A depth-capacity curve for digestion and sludge storage tanks.
4. A kilowatt-monthly power bill curve for estimating power bill on certain rates.
5. Plant data for easy reference to elevations, capacities, rates of flow, etc., orifice meter constants.
6. Conversion data frequently used.
7. Handy equations.
8. Telephone numbers most frequently used.
9. Decimal equivalents of common fractions.
10. Pipe diameters, I.D.

There follows a summary of some of this data which is indicative of how the operator may build up his own table top.

CONVENIENT DATA UNDER YOUR GLASS TABLE TOP

Plant Data for Easy Reference

Part of Plant	Elevation	Capacity, Equations, Data
Grit Chamber		
Roof	608.93	Detention 90 sec.
Floor	601.43	
Imhoff Tanks		
Top	604.5	Sett. Cap. = 63,700 cu. ft.
Sludge Channels	598.0	Detn. Period = 11.44/m.g.d.
Outlet Weirs	602.5	Total Sl. Cap. = 6,500 cu. yds.
		1 ft. drop, 1 tank = 62.8 cu. yds.
Sludge Beds		
Sand Elev.	592.0	Area = 55,000 sq. ft.
Channel Top	595.3	1 bed 12 in. sludge = 93 cu. yd.
		13 in. sludge = 100 cu. yd.
		14 in. sludge = 108 cu. yd.
		15 in. sludge = 116 cu. yd.
Industrial Track	592.18	
Digestion Tank		
Top	615.0	1 ft. depth = 72.5 cu. yd.
Bracket	600.0	Cone 4 ft. = 109.0 cu. yd.
Top Cone	590.0	
Bottom	586.0	
Cover Floats at	602.06	
Sludge Pump Cap. per Stroke		0.456 cu. ft.
Aeration Tanks		
Top	603.3	Detn. Per. = $\frac{30.3}{\text{m.g.d.}}$ 6 tanks
Bottom	586.8	
Pipe Gallery	589.5	= $\frac{20.2}{\text{m.g.d.}}$ 4 tanks
Dorr Tanks, Bottom	588.2	
Dorr Tank Weirs	601.6	Dorr Detn. Per. = $\frac{28.6}{\text{m.g.d.}}$ 2 tanks
		= $\frac{14.3}{\text{m.g.d.}}$ 1 tank
Dosing Tank Wiers	601.25	Each tank 48,000 to 56,000 gal. per spray
Sprinkling Filters		
Top Stone	595.1–594.3	3 acres
Bottom Drain	588.2–587.4	Avg. depth 6 ft. 130,800 sq. ft.
		783,000 cu. ft.
		29,000 cu. yd.
Secondary Settling Tanks		
Top	593.0	Det. Per. = $\frac{4.98}{\text{m.g.d.}}$
Bottom	574.89	Sur. rate = $\frac{14,500}{\text{m.g.d.}}$
Weirs	585.98	
Pump House Floor	595.8	
Office Bldg.		
Basement Floor	597.5	
1st Floor	606.0	
2d Floor	615.38	

CONVENIENT DATA UNDER YOUR GLASS TABLE TOP—*Continued*

Part of Plant	Elevation	Capacity, Equations, Data
Dike Top	602.0	
Effluent Man Hole, Top	602.2	

Fox Boro Gas Orifice Meter

1 in. orifice 1 maj. scale div. = 16,700 c.f.d., 7 day factor 2,090
1.25 in. orifice 1 maj. scale div. = 24,200 c.f.d., 7 day factor 3,020
1.5 in. orifice 1 maj. scale div. = 34,800 c.f.d., 7 day factor 4,350

Digestion Gas Meter (small) .5 in., orifice

0/24 hr. = 5,360 $\sqrt{h'' H_2O}$
1/24 hr. = 5,360 cu. ft. 24 hr.
2/24 hr. = 7,600 cu. ft. 24 hr.
3/24 hr. = 9,300 cu. ft. 24 hr.

There are many complete conversion tables in most handbooks but I keep the following under the glass for easy reference.

Length 1 in. = 2.54 cm.
1 yd. = .304 meter
1 mile = 1.61 Kilom. = 5,280 ft.

Area 1 acre = 43,560 sq. ft.
1 sq. mile = 640 acres = 27,880,000 sq. ft.
1 sq. M. = 10.764 sq. ft. = 1.196 sq. yd.

Volume 1 gal. = 231 cu. in. = 3.785 l. (H_2O) = 8.34 lb.
1 cu. ft. = 1,728 cu. in. = 7.48 gal. = 62.3 lb. (H_2O)
1 cu. yd. = 27 cu. ft. = 202 gal. = 1,684 lb. (H_2O)
1 cu. yd. (earth) 2000–3000 lb. sludge = 2000 lb.
(sand) = 1600
(Gravel) = 1600
(Cement) = 5300
1 acre ft. = 325,850 gal. = 43,560 cu. ft.
3.07 acre ft. = 1,000,000 gal.

Flow 1 m.g.d. = 1.547 cu. ft. sec. = 694.44 gal./min.
1 sec. ft. (c.f.s.) = 646,272 gal. per 24 hrs.
1 in. rain on 1 sq. mile = 17.4 million gal. (100%)

Velocity 1 mile per hr. = 1.467 ft. per sec.
1 ft. per sec. = .682 miles per hr.

Pressure 1 inch H_2O = 0.036 lb. per sq. inch = 0.577 oz.
1 ft. H_2O = .433 lb. per sq. in. = .029 atmosphere
1 lb. per sq. in. = 2.307 ft. of H_2O = .068 atmosphere
1 atmosphere = 33.90 ft. H_2O = 14.7 lb. per sq. in.
1 ft. H_2O = .883 in. Hg
1 inch Hg = 13.59 in. H_2O = 1.13 ft. H_2O = .49 lb. per sq. in.

Power 1 K.W.H. = 1.34 H.P.
1 H.P. = 746 watts = 33,000 ft. lb. per min. = 42.41 B.T.U. per min. = 2545 B.T.U. per hr.

Weight 1 oz. = 28.35 grams
1 lb. = 453 grams
1 kg. = 2.02 lb.

Misc. 1 p.p.m. = 8.34 lb. per mil. gal.
1 gr. per. gal. = 17.1 p.p.m. = 142.5 lb./mil. gal.
100 lb. per mil. gal. = .7 g.p.g. = 12 p.p.m.
1 candle power = 1.2 watts
pop. eq. = p.p.m. × m.g.d. × 49
Lb. per 24 hr. = p.p.m. × m.g.d. × 8.34

Formulae—Calculations

Orifice and Venturi Meter Flows, $\sqrt{U_2^2 - U_1^2} = C\sqrt{2g\Delta H}$

Rectangular Weirs, $\frac{V}{\text{sec.}} = 3.33\ (L - .2H)H^{3/2}$

V-Notch Weirs, $\frac{V}{\text{sec.}} = 2.505\left(\tan\frac{a}{2}\right)^{0.996}H^{2.47}$

Friction in Pipes, $\Delta Pf = \frac{2fLpu^2}{gD}$ (Fanning Curve)

$$\frac{\Delta PfD}{u^2pL} = \frac{\Delta HfD}{u^2L} \text{ (Straton Curve)}$$

also, $$\Delta Hf = \frac{\Delta P}{p}$$

$$Re = \frac{Dup}{\mu}$$

Heat Transfer

Convection—$h = 50\sqrt[3]{J\Delta t°f} = 50\sqrt[3]{(1/z)t°f}$

$$\frac{Q}{\theta} = hA\Delta t \text{ or } HA\Delta t$$

H in still air	1.34	
H in outside air	3.2	10 mile.
H in outside air	4.2	20 mile.
H in air space insulation	1.1	B.T.U. per sq. ft./$f°$

THE COMMINUTION OF SEWAGE SOLIDS *

By Philip F. Morgan

Sanitary Engineer, Chicago Pump Company, Chicago, Illinois

The solids in sewage which are large enough to be retained on a conventional bar screen represent only a very small portion of the total sewage flow, but the problem of handling these solids demands considerable attention.

These solids normally consist of pieces of paper, cloth, garbage, sticks, and fecal matter, if the sewage is in a fresh condition, and in addition may contain almost anything which can be flushed down a sewer.

If these solids are disregarded they may clog or injure pumps, valves, sludge removal equipment or any other mechanical equipment in a sewage treatment plant. In primary settling tanks and digesters the entrainment of gas bubbles in the large solids will cause them to float to the surface thus forming scum which may be a real problem in itself, particularly if it becomes thick and tough. The floating of large solids on the surface of primary tanks is also objectionable because of its unsightly appearance. Many other problems may also develop if the large sewage solids are allowed to enter a treatment plant in their original condition.

Prior to 1933, and in many plants built since then, the coarse sewage

* Presented at the Fourteenth Annual Meeting of the Arizona Sewage and Water Works Association, Tucson, Arizona, April 20, 1940.

solids were removed by screens. Regardless of the size of the plant the coarse solids are collected on screens or racks and at frequent intervals must be removed, by hand in the smaller plants, or mechanically in the larger plants. The screenings thus removed are then disposed of by any number of methods. At the smaller plants they are usually buried. In some of the larger plants screenings have been centrifuged and incinerated, but this has not proven entirely satisfactory because of the larger amount of labor required and the attendant mess, odor and cost. Special acid digestion tanks have been constructed for the digestion of screenings, but have not been adopted on a large scale, possibly because they do not simplify the operation of the plant; in fact, they add to the total amount of labor and plant control required. Dumping on large piles has been practiced at a few plants, but needless to say, this practice becomes a public nuisance.

Since none of the methods of separate disposal of sewage solids are entirely satisfactory it is obvious that the attempt should be made to change the form of the sewage solids so they can enter the primary tank with the sewage and be handled as part of the primary sludge. This was first accomplished by collecting the screenings on a conventional bar screen, grinding them and returning the ground screenings to the influent sewer. The quantity of screenings removed by screens with various sized openings are shown in Fig. 1, taken from Metcalf and Eddy.

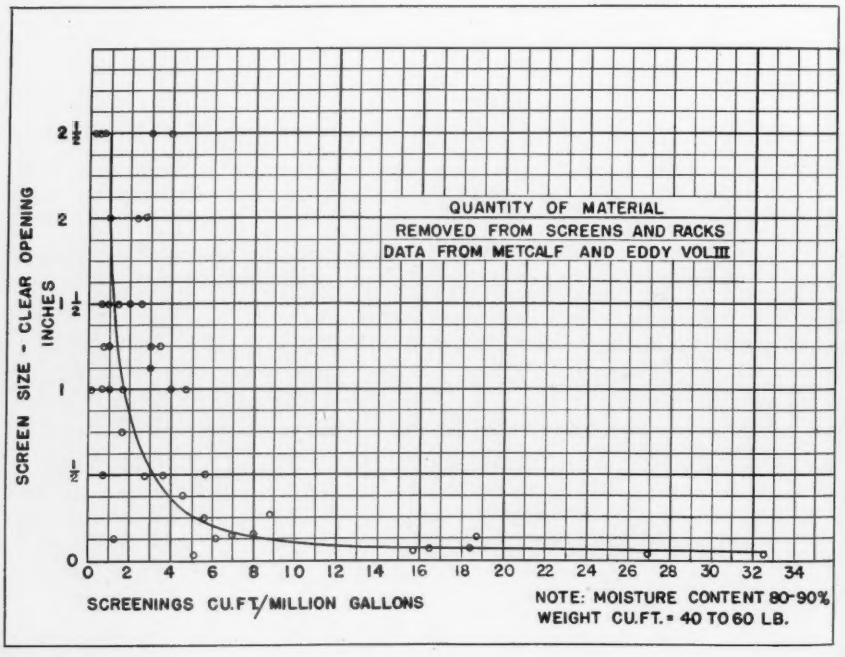
SCREEN SIZE - CLEAR OPENING INCHES
2½
2
1½
1
½
0
QUANTITY OF MATERIAL
REMOVED FROM SCREENS AND RACKS
DATA FROM METCALF AND EDDY VOL III
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
SCREENINGS CU.FT./MILLION GALLONS
NOTE: MOISTURE CONTENT 80-90%
WEIGHT CU.FT. = 40 TO 60 LB.

FIG. 1.

The Comminution Process

When the comminution process is adapted to a sewage treatment plant the coarse matter in the sewage is cut or chopped into small pieces beneath the sewage surface as the sewage flows into the plant, thus entirely eliminating one phase of the sewage treatment process. The comminuted material flows into the primary sedimentation tank where it settles out and becomes part of the primary sludge. Since the solids have been cut into pieces small enough to pass through 3/16 in., 1/4 in. or 3/8 in. slots they will no longer cause difficulty with mechanical equipment, and they are small enough so that settling is rapid and complete.

The width of the slots varies for the different units from 3/16 in. to 3/8 in. for the largest. With these slot widths the comminutor will cut all solids that can be considered coarse sewage solids.

A comminutor is installed in a specially constructed section of the raw sewage channel at the inlet to the sewage treatment plant; complete installations consisting of a comminutor, the comminutor basin or section of channel in which the comminutor is installed, the approach channel to the basin, and the discharge channel from the basin.

In operation the sewage flows into the comminutor basin, through the narrow slots in the revolving drum, out the bottom of the drum, and into the discharge channel (Fig. 2). The solids which are too large to pass through the slots are held against the surface of the drum by the velocity of flow through the drum slots. As the drum rotates, the shear-

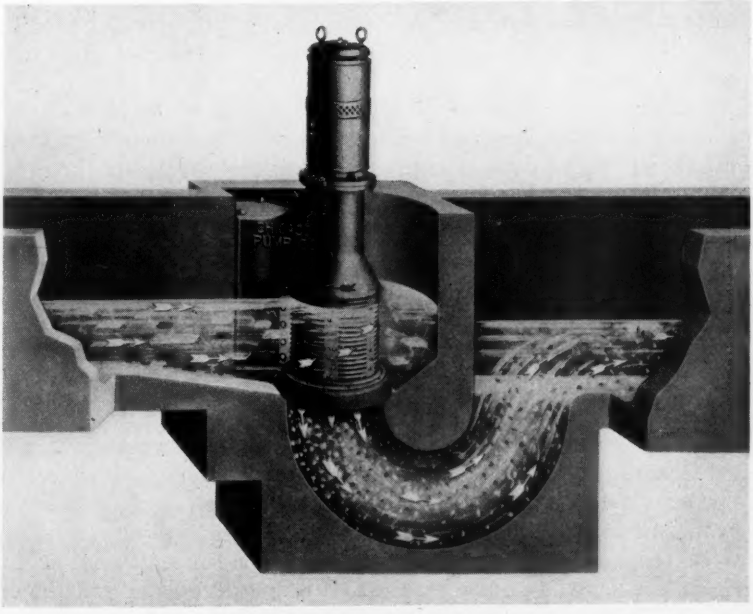

Fig. 2.—Communitor installed in influent channel.

ing action between the teeth on the drum and the comb on the stationary post cuts these larger solids into pieces small enough to pass through the slots.

Maintenance.—The teeth on the drum are cast stellite and the shear bars on the drum and the comb on the stationary post are stellite-faced, to resist wear. Stellite is one of the hardest alloys known.

The required maintenance of a comminutor consists of a weekly lubrication of the shaft bearings, weekly inspection of the cutting surface and occasional lubrication of the motor and reducer. When the stellite cutting surfaces on the teeth, combs or shear bars become dull, these parts are changed. The teeth receive the most wear but can be sharpened several times before being replaced. The length of time before it is necessary to sharpen them depends entirely upon the amount and type of grit in the raw sewage and the location of the teeth on the drum. The lower teeth may have to be resharpened and replaced anywhere from every few weeks to only once every year or two. The upper teeth will remain sharp much longer than the lower. It is obvious from this that the amount of time required for maintenance of a comminutor is a negligible quantity.

Installation.—Comminutors are available in various sizes from the smallest unit with a 7-inch diameter drum and a capacity up to 350,000 g.p.d.; to the largest size with a 36-inch diameter drum and a capacity up to 25,000,000 g.p.d. The cutting capacity of each machine greatly exceeds the normal solids load carried in the sewage. For example, the 25A machine has the capacity to comminute approximately 18 times the amount of solids normally contained in the sewage flow which can be handled by the machine. Consequently, the machines are rated on the basis of sewage flow.

The smallest unit is supplied with a cast-iron basin so that no special concrete work is required. The other units are installed in special concrete basins designed so the sewage solids are carried to the machine for comminution by the sewage as it flows through the slots in the revolving drum. The exact dimensions for the comminutor basin are furnished with each machine as part of the installation drawings.

The Channel Structures

The particular arrangement of channels, the number of comminutors to install, and the value of installing a bar screen by-pass is dependent upon the individual problem.

Single Comminutor and Bar Screen.—Where one comminutor is installed to handle the total flow, it is recommended that a bar screen by-pass be provided so the flow can be diverted through the bar screen when it becomes necessary to inspect the comminutor, install new teeth, etc.

With the bar screen by-pass, particularly for the smaller plants which do not have 24-hour operation, it is possible to adjust the elevation of the gates to the by-pass so that in the event of a power failure

the sewage will automatically pass through the bar screen and on into the plant. When power is restored the comminutor will continue its normal operation.

Where a town has combined sewers, excessive storm flows may be encountered. For an economical and practical installation the comminutor is selected for the normal flow and the by-pass gate is set so the excess storm flow will automatically pass through the bar screen. During periods of storm flow, screenings may be periodically removed from the screen and placed in the comminutor basin for comminution.

Duplex Installation.—Comminutors are often installed in pairs so one may act as a stand-by unit. The second comminutor in addition to acting as a stand-by unit can, if necessary, be used to handle peak storm flows.

Duplex installations are particularly applicable for installation where future flows are to be much greater than present flows. This condition is often encountered where a town is only partially sewered and extensions are anticipated, and also in suburbs of industrial areas where rapid growth can be expected. One machine can handle the present flow and act as a stand-by unit. Both machines can be used for future flows.

Large seasonal variations in flow from seasonal industrial wastes can be handled in the same way.

Multiple Installations.—Any number of the large-sized comminutors may be installed where the average flow will exceed 30 to 40 m.g.d. Multiple installations of smaller units may also be used, if desired, to meet certain flow conditions and to give flexibility in operation.

The Function of Comminutors

The great majority of comminutors are installed as a part of the sewage treatment plant to protect the mechanical equipment in the plant, but there are also many installations in outlying pumping stations to protect the pump and prevent clogging. At pumping stations the comminutor basins are constructed over the wet well and the motor is installed on a motor floor above high water or is mounted directly on the comminutor. The sewage after passing through the comminutor falls directly into the wet well.

Installations have been made for the comminution of sewage solids previous to discharge to bodies of water for treatment by dilution. This is done to eliminate the possibility of large sewage solids being carried great distances beyond the point where self purification would normally take place and to reduce the amount of scum on the receiving body of water. At Nice, France, where the installation was for this purpose, the operating reports indicate very satisfactory results. In fact, the results are much better than anticipated.

Factors to Consider When Installing Comminutors

For the most satisfactory comminutor installation at a new plant or at an existing plant the correct size machine must be selected for the flows which are to pass through it, and the elevation of the comminutor basin must be correctly established in relation to the upstream and downstream structures. In short, the comminutor is installed so carrying velocities will be maintained in the channel or sewers as the sewage flows to the machine for comminution and hence carrying velocities will be maintained downstream from the machine so the comminuted material will be carried on its way with the sewage.

The required liquid level differential between the upstream and downstream sides of the comminutor is a variable depending upon the flow and the machine. In general it is only slightly more than the liquid level differential required for a conventional bar screen; the majority of installations operating with 4 to 10 inch differential. Hydraulic characteristics curves showing head differentials and flow data are available for all units as well as recommended layouts for all types of installations.

Editorial

BOOKS ON SEWAGE DISPOSAL

During the past two years a number of notable books have appeared in the field of sewage disposal. In fact, more books have been published since 1938 on this subject than in the previous 10 or 15 years. In 1935 a new edition of Metcalf and Eddy's *Disposal of Sewage* appeared, and it still remains the most satisfactory and authoritative book in the field, although getting a little out of date. Prior to this book, the single-volume text-book of Metcalf and Eddy *Sewerage and Sewage Treatment* had appeared early in the thirties, Fuller and McClintock's *Solving Sewage Problems* about 1925, Babbitt's *Sewerage and Sewage Treatment* in several editions between 1922 and 1932, and Kinnicutt, Winslow and Pratt's *Sewage Disposal* in 1919. Other American books of minor importance also were published at intervals between 1919 and 1938, but never before has such a crop of first-class book appeared as during the past two years.

There are probably several reasons for this influx of books, among them the unparalleled advance in sewage research and sewage treatment in the thirties, the improving economic conditions since 1933, the influence of the PWA in stimulating sewage works construction, and probably the integration by the Sewage Works Federation of a distinctive group of sewage works men, eager for information on sewage treatment. Whatever the causes, the new books have been received with interest. Fortunately the fields of interest of the recent books have been varied; one appears to be designed for operators, another for research workers, another for teachers, and another for all classes of workers in sewage disposal (*Modern Sewage Disposal*). A few personal observations, which of course may not coincide with the opinions of others, might help to explain the types and values of the various books in this field.

Sewage Treatment Works by C. E. Keefer is a book expressly designed for operators (see Review in this issue). It has all the detail and scope of an encyclopedia, and will be very helpful as a reference book, but it presents too many viewpoints, and in some cases conflicting conclusions of research workers, to be useful as a textbook. Practice is faithfully recorded, but the reader is swamped in detail, and therefore the book does not read easily and consistently. In these characteristics it is the antithesis of Imhoff and Fair's *Sewage Treatment* (reviewed in the November, 1940, issue) which has been trimmed of all detail and endowed with the viewpoint and conclusions of its distinguished authors, so that it presents an authoritative picture of what is best in sewage practice. *Sewage Treatment* is hardly a book for the inexperienced engineer, however, or for classroom use. To appreciate this work, one must realize the selectivity and discrimination necessary to compress it to its brief compass. It is a book to teach the teacher, not the student.

Professor Babbitt's book *Sewerage and Sewage Treatment* (reviewed in this issue) is a very practical book for teachers, operators, engineers and students. It is readable, consistent and interesting, but deserves better editing.

The Federation Anniversary Book, *Modern Sewage Disposal,* is unique in that it virtually comprises the scientific memoirs of its 32 contributors, and thus presents an authoritative picture of their various fields of interest. It should be

read and re-read, just as one views paintings or works of art frequently, to develop appreciation of the work of master craftsmen and to obtain renewed stimulation and inspiration.

The remarkable book by the Australian from Glenelg, Mr. Henry J. N. Hodgson, entitled *Sewage and Trade Wastes Treatment* is probably unavailable to most sewage workers, because it was printed in 1938 as a private report to the Government of South Australia. This Report of 534 pages contains a great amount of detailed information on sewage and trade waste treatment in the U. S., England, Germany and Australia, as collected by the author during his extended visits in these countries. It is unique because it contains critical evaluation of all that is new, with the very sound and unbiased conclusions of the author.

One of the outstanding books in the world on sewage treatment and industrial wastes is Dr. F. Sierp's book (in German) on *Technology of Water,* published in 1939. It contains 208 pages on water, 280 on sewage and 230 on industrial wastes. This book is probably even rarer than Mr. Hodgson's in the United States, but these two contain the best material available on industrial wastes. Another German book that must be mentioned is Brix, Imhoff and Weldert's vast work *Sewage Disposal in Germany,* in two volumes, the second of which includes a description in some detail of all sewage treatment works in Germany.

English books on sewage treatment have appeared infrequently in recent years. There is the book by Francis published some seven or eight years ago, and Arthur J. Martin's *The Activated Sludge Process,* published in 1927. Both of these authors have died, Mr. Martin quite recently. English literature on sewage treatment is of course quite extensive and many standard works were published years ago.

In America, several other books are available, with various points of view, for example those by Hardenbergh, Buswell, Steel, Fuller and McClintock and Kinnicutt, Winslow and Pratt. For all purposes, however, the writer prefers Metcalf and Eddy's *Disposal of Sewage* because it is well balanced, authoritative, useful either as a textbook or a reference book, and finally, because it is the major work of the most distinguished engineer in the history of American sewerage practice, Mr. Harrison P. Eddy.

F. W. MOHLMAN

Proceedings of Local Associations

CALIFORNIA SEWAGE WORKS ASSOCIATION

Thirteenth Annual Fall Convention

San Diego, California, September 15–17, 1940

President Harold G. Smith assembled the group in the Colonial Room of the Hotel U. S. Grant at 6:45 P.M. on Sunday September 15. Mr. A. L. Dopmeyer, U. S. Public Health Service, read a paper entitled, "Ohio River Pollution Survey, First Year's Work," prepared by H. R. Crohurst and E. S. Tisdale of the Public Health Service. The paper was supplemented by a film illustrating the many points of the paper.

Dinner was served in the Gold Room and a program was provided by the operators. A number of short talks with lantern slide illustrations were presented.

President Smith called the business meeting to order at 9:50 A.M. on Monday, September 16. Nominations for officers were submitted as follows:

President.....Harold F. Gray
First Vice-President.....Fred D. Bowlus
Second Vice-President.....Carl M. Hoskinson
Secretary-Treasurer.....William T. Ingram
Member Governing Board, 1945.....Albert J. Castro, Jr.

It was moved, seconded and carried that the report of the nominating committee be accepted. These officers were unanimously elected, and it was recommended that A. L. Frick be appointed to the Board of Control.

Proposed amendments to the constitution were read and the amendments passed.

The following reports were called for and given:

Membership.....Jack H. Kimball
Finance.....J. F. Smith
Publicity.....John A. Clark
Legislative.....Howard Jewell

The business meeting adjourned until Tuesday noon. The technical sessions were started, and the following papers were presented.

"Development of Cannery Waste Studies at Palo Alto, Calif." Jack H. Kimball; Harold May.

"Current Developments and Trends in Sewage Treatment." A. J. Fischer. Discussion—Harold F. Gray.

"Application of Present Sewage Legislation." Homer F. Buckley.

The meeting adjourned to lunch at which time Councilman A. Flowers of San Diego welcomed the Association to San Diego. President Smith responded .

F. Carlyle Roberts, Secretary-Treasurer of the Arizona Water and Sewage Works Conference, extended a word of greeting and invited all those who could, to come to Safford, Arizona, October 4th, 5th, and 6th.

The technical sessions resumed at 2 P.M. At this time, a moment of pause was given in memory of A. K. Warren, Chief Engineer, Los Angeles County Sanitation Districts and charter member of the California Sewage Works Association, who passed away August 28, 1940.

Short discussions were given on the operators panel by Carl F. Tennant and F. Wayland Jones. The Secretary read a contribution by Bernard Rowntree, and A. E. Fiscus read a paper prepared by W. V. Skinner.

Papers were presented as follows:

"Proposed Disposal of Sacramento Sewage." Prepared by Carl Hoskinson, read by C. R. Blood.

"Electrolysis at Terminal Island Treatment Plant." G. A. Parkes. Discussion—Richard Pomeroy.

"Public Health Considerations Regarding San Diego County Sewage Disposal." G. C. Zuckweiler.

"History of California Sewage Works Association." C. G. Gillespie; E. A. Reinke.

There was a lively discussion from the floor on the above papers. The meeting adjourned at 5 P.M. to the annual banquet.

The banquet to which the city engineers' department of the League of California Cities was invited was marked by the appearance and short address of Commander H. S. Baer, U. S. N.

A fine entertainment was presented in "Ye Olde Time Vauderville," by a selected cast of San Diegans.

On Tuesday, September 17, the city engineers and street superintendents department of the League of California Cities and the California Sewage Works Association assembled at a joint breakfast. Mr. Elmendorf, Chairman of the City Engineers, asked Mr. Alfred Jones, Los Angeles County Surveyor, Mr. E. S. Gripper, District Engineer, State Highway Department, and Mr. B. D. Phelps, Asst. City Engineer, San Diego, to give short discussions. Albert J. Castro discussed the work of the California Sewage Works Association Award Committee. The Committee recommended that no award be made for the year 1940.

Technical sessions resumed at 9:35 A.M. Papers presented were:

"Sewage Pumping Plant Operation"—F. A. Batty.

"Sewer Maintenance Problems"—Lyle Payton.

"Problems of Industrial Waste from the Standpoint of City Administration"—W. T. Knowlton. Discussion—William T. Ingram; Albert J. Castro.

"Legal Aspects of Sewer and Storm Drain Maintenance"—Hugh MacDonald—Read by Mr. Davis.

The meeting adjourned to luncheon. After lunch, President Smith called the business meeting to order.

The Secretary presented a report of the constitutional amendment committee.

F. Wayland Jones presented a report of the San Joaquin Section of the California Sewage Works Association.

The Secretary's report was read.

Adolph H. Koebig presented the report of the Auditing Committee.

Albert Castro presented a supplemental report of the Award Committee.

The Secretary read a report of the Sub-Committee on Schools for Operators, and Mr. C. G. Gillespie reported for the Sub-Committee on Certification of Operators.

Richard Pomeroy reported for the Committee on Design Practice.

Two resolutions were presented to the meeting. The first was a Resolution relative to National Defense. The second was relative to cross connections of sewage and water in sewerage systems. Both had been previously approved by the Governing Board. It was moved, seconded and carried that they be adopted.

Mr. A. C. Beyer explained the proposed changes which were to be considered by the Federation of Sewage Works Associations. It was moved, seconded, and carried that Messrs. Alexander Bell and J. F. Byxbee be sent a Resolution of regret and sympathy for their long illness.

The new officers were then installed and President Smith transferred the chair to President Gray.

After a brief address, President Gray adjourned the meeting at 1:45.

WILLIAM T. INGRAM, *Secretary*

NEW ENGLAND SEWAGE WORKS ASSOCIATION

Eleventh Annual Fall Meeting

Springfield, Massachusetts, October 15–17, 1940

The eleventh annual fall meeting of the New England Sewage Works Association was held on October 15–17, 1940, at the Hotel Kimball in Springfield, Massachusetts. Two hundred and sixteen members and guests, which included thirty-four ladies, were registered for the meeting, which again established an all-time record for an attendance at any meeting.

On Tuesday, October 15, the manufacturers' exhibit area was open for inspection. This proved to be the largest exhibit yet held by the Association. Twenty-five manufacturers exhibited sewage treatment

plant equipment. A meeting of the executive committee was held in the evening.

On Wednesday, October 16, the business meeting was called to order by President Arthur D. Weston at 9:45 A.M. Messrs. Gilcreas and Emerson briefly discussed the new Federation setup, the Secretary-Treasurer read his reports, and the election of 1941 officers was held. The following men were elected:

President—Walter J. Shea, Providence, R. I.
First Vice-President—Samuel M. Ellsworth, Boston, Mass.
Second Vice-President—R. H. Suttie, New Haven, Conn.
Secretary-Treasurer—LeRoy W. Van Kleeck, Hartford, Conn.
Directors—Herbert B. Allen, Fitchburg, Mass.
Walter M. Kunsch, Danbury, Conn.
Leonard W. Trager, Concord, N. H.

The first speaker during the morning session was Mr. Robert K. Horton, Investigator, Textile Foundation, Chapel Hill, North Carolina, who spoke on "The Disposal of Textile Wastes with Domestic Sewage."

The second paper was presented by Mr. Richard Dudley, Deputy Superintendent of Engineering, Department of Streets and Engineering, Springfield, Massachusetts, on "The Springfield Sewage Treatment Project."

The concluding morning event was a symposium on sewer pipe materials and jointing compounds, conducted by Mr. Harold L. Brigham, Superintendent, Water and Sewer Commission, Marlboro, Massachusetts.

Following luncheon at the Hotel Kimball, there were brief comments on the Springfield sewage treatment plants by Mr. C. A. Emerson, Consulting Engineer, Havens and Emerson, Cleveland, Ohio. His comments were followed by field inspections of the York Street pumping station, the Bondi Island main sewage treatment plant and the Indian Orchard sewage treatment plant, all operated by the city of Springfield. A few of the members also visited, during the late afternoon, the Springfield Arsenal.

The annual banquet was held at 7:00 P.M. in the ball room of the Hotel Kimball. A photograph of the group was taken and the secretary has placed one on file in the Association archives.

The guest speaker following the evening banquet was Mr. W. H. Woodward, Testing Engineer for the City of Springfield, who presented a very interesting talk on "Shadows in the Hindustan Himalayan Jungle." Dancing followed.

On Thursday, October 17, there was an operators' sunrise breakfast and Question Box, at which time the gadgets submitted for the gadget contest were explained by the entries. This proved to be a very interesting hour. The following operators were awarded prizes:

Mr. William J. Hanrath, Pittsfield, Mass.—1st prize.
Mr. Charles H. Copley, New Haven, Conn.—2nd prize.
Mr. William Lannon, Putnam, Conn.—3rd prize.

Mr. Walter J. Shea, Second Vice-President, was the leader during the Question Box hour. In the absence of Mr. Frank Barbour, consulting engineer, Boston, remarks on the Amherst sewage treatment project were made by Mr. Robert R. Balmer, Jr., of the Massachusetts Department of Public Health. The Association members then left for Amherst, Massachusetts, for an inspection of the municipal sewage treatment plant. Many of the ladies accompanied the men on this inspection.

At 12:45 P.M. a men's and ladies' luncheon was served the Association at Wiggins' Tavern in Northampton, Massachusetts. Mr. Leonard W. Trager, chairman of the committee to investigate the practicability of editing a journal by this Association, made a progress report at this luncheon. He believed that financially such a journal would be successful. A further report is expected from his committee.

Following the luncheon, the ladies visited the grounds of the Tavern, while the men listened to brief comments on the Greenfield sewage treatment project by Mr. Frank Flood, consulting engineer with Metcalf and Eddy of Boston, Massachusetts. Mr. Flood's talk was followed by an inspection trip to Greenfield, Massachusetts, for a visit to the municipal sewage treatment plant. This completed the technical program.

On Wednesday, October 16, the ladies were served luncheon at Storrowton Tavern and inspected Storrowton Village following the luncheon. They were also taken for a brief bus tour ending at the city museum center. The ladies were present during the evening banquet and entertainment.

The manufacturers' exhibits were well attended throughout the meeting and this part of the program was the most successful of any meeting held to date. All of the technical sessions were also well attended. Attached with this report is a mimeographed list of those registered for the meeting.

Mr. Paul V. Fleming, operator of the North Adams, Massachusetts plant, brought up a question at the operators' Question Box on salaries paid operators. He stated in many cases the designing engineer has the first word as to what salary should be paid and that a fair schedule of wages should be set up. He also expressed dissatisfaction in procuring raises for deserving operators. Second Vice-President Shea suggested that the executive committee might appoint a committee to study this matter and report to the Association.

LeRoy W. Van Kleeck, *Secretary*

CANADIAN INSTITUTE ON SEWAGE AND SANITATION

Seventh Annual Convention

Toronto, Ontario, October 24–25, 1940

The seventh annual convention of the Canadian Institute on Sewage and Sanitation held in Toronto on October 24–25, proved to be a successful meeting in spite of troubled world conditions. The registration was 138. New members received brought the total membership of the Institute to 131, the highest yet attained.

This year's meeting included a program of written papers and "Guided Discussions." The four papers were delivered on the afternoon of the first day. The first of these, given by S. A. Greeley, consulting engineer of Chicago, was entitled "Trends and Newer Features in Sewage Treatment." This comprehensive paper outlined the developments in this field, and showed the extent of treatment, and the methods and equipment available.

The second paper, dealing with the subject of "Treatment and Control of Industrial Wastes," was delivered by Milton P. Adams, executive secretary-engineer of the Michigan Stream Control Commission. The paper contained a description of the program in the State of Michigan, as well as some of the problems in disposal of different industrial wastes.

W. C. Miller, City Engineer of St. Thomas, Ont., gave a paper on the "Present Status of Refuse Collection and Disposal." In this he referred to some extent to financial problems in this field, and also discussed developments in equipment and methods.

The final paper, entitled "Sewer Construction Problems" was presented by W. H. Collins, sewer engineer of Hamilton, Ont. This contained an outline of construction problems which arise in work of this kind.

The business meeting of the Institute saw the election of the following executives:

Past-President—W. H. Riehl, Stratford.
President—S. Shupe, Kitchener.
Vice-President—W. L. McFaul, Hamilton.
Trustees—B. F. Lamson, St. Catharines; H. S. Nicklin, Guelph.
Secretary-Treasurer—A. E. Berry, Toronto.

"Guided Discussions" occupied a prominent part of the program. In this, a series of questions, listed under the following five subjects, were considered by the delegates. Certain members were asked to lead in these discussions and then each question was open to the meeting. The subjects and their chairmen were as follows:

1. "Financing Street Oiling and Cleaning"—*Chairman,* S. Shupe, Kitchener.

2. "Weed Control in Urban Centres"—*Chairman,* H. D. Bradley, Toronto.
3. "Disposal of Sludge in Wet State"—*Chairman,* H. S. Nicklin, Guelph.
4. "Chlorine in Sewage Plant Operation"—*Chairman,* J. B. Baty, Kingston.
5. "Public Relations"—*Chairman,* F. P. Adams, Brantford.
6. "Sewage Pumping Stations"—*Chairman,* W. L. McFaul, Hamilton.

Social functions at the convention included a dinner and entertainment on opening day, followed by a luncheon on the second day. At the latter, greetings were extended from representatives of the cities of Toronto, Hamilton, and Stratford. The presidents' Certificate of the Institute was presented to the immediate past president, W. C. Miller, the presentation being made by R. C. Harris, the first president of the Institute.

Next year's meeting will be held at Kitchener, Ontario.

A. E. Berry, *Secretary*

SOUTH DAKOTA WATER AND SEWAGE WORKS CONFERENCE

Sixth Annual Meeting

Mitchell, South Dakota, October 17–18, 1940

The sixth annual meeting of the South Dakota Water and Sewage Works Conference, which was held at Mitchell on October 17 and 18, was the most successful meeting in the short history of this organization. The total registration was one hundred and five, eighty-eight of this number being members. Fifty-nine of those members present were persons actively associated with the operation and maintenance of water and sewerage systems. These operators, superintendents, engineers and chemists represented forty-one different municipalities and institutions having water and/or sewerage systems. Ten Indian agencies sent their representatives. The following papers dealing with various phases of sewerage and sewage treatment were presented:

"Operation of Small Sewage Treatment Plants" by Charles Carl, Instructor in Sanitary Engineering at South Dakota State College. Mr. Carl stressed the advisability of the operator paying close attention to his plant, even though it is small and apparently may need little care. The careful conduct of routine operation problems often forestall more serious difficulties. It is particularly essential to keep the plant clean at all times. A clean plant is invariably a well operated and well functioning plant, and the owner is receiving the maximum returns on his investment.

A paper entitled "Some Sludge Digestion Problems and Their Solution" was prepared by D. C. Reybold of the Dorr Company, Chicago,

Illinois. Mr. Reybold was not present but the paper was read by the Secretary. Several rules were presented by Mr. Reybold to be used as a guide for good digester operation.

Mr. C. C. Dugan of the Garlock Packing Company gave a talk on the "Use and Application of Packing the Water and Sewage Pumps." He stressed the part that pump packings play in the efficient operation of the pump, and the necessity for choosing a packing designed for the type of liquid which is being pumped. He also gave timely suggestions regarding the care and maintenance of packing glands to insure longer life and greater efficiency.

Mr. Alfred Ross, Superintendent of the Huron sewage treatment plant, and Mr. W. H. Buck, Assistant Engineer of the State Board of Health, presented a joint paper relative to increasing sewage treatment efficiency by recirculation of filter effluent to the primary tank. The Huron sewage treatment plant, consisting of primary clarification with separate sludge digestion, and trickling filters, fixed spray nozzle type, receives a waste made up of domestic sewage and packing house wastes. On a quantity basis, the plant is now over-designed. However, the strength of the waste is such as to result in an effluent insufficiently purified to eliminate nuisance conditions in the receiving stream, which at the present time has little or no flow.

In addition to the papers, one full afternoon was devoted to sectional meetings including a sewage treatment section, a water treatment section, and a general water supply section. Considerable discussion developed at all of these meetings, and the operators were all of the opinion that such meetings were most beneficial.

The City of Mitchell was host to the Conference at a Dutch Lunch at noon on the first day and the banquet, held the evening of the first day, was attended by one hundred and nine persons. The meat course was pheasant which the Mitchell water and sewage works operators had provided. The moving picture "Behind the Water Tap," property of the Industrial Chemical Sales Company, provided part of the banquet entertainment. Other entertainment consisted of a male quartet and a sleight-of-hand artist. The magician did not attempt, however, to reach in the hat and remove some of the problems confronting several sewage treatment plant operators.

An inspection trip was arranged to both the water treatment plant and the sewage treatment plant. Considering the time of day, 9:15 A.M., it was very well attended.

Prominent out-of-state guests included Frank R. Shaw, Senior Sanitary Engineer, U. S. Public Health Service, Chicago, Illinois; and Mr. T. A. Filipi, State Sanitary Engineer, Lincoln, Nebraska.

At the business meeting on the afternoon of the last day, the Conference adopted a resolution requesting the coöperation of the State Board of Health and the state institutions of higher learning in inaugurating a series of short courses for water and sewage treatment plant operators.

The Conference also endorsed state participation in a stream gauging program in coöperation with the U. S. Geological Survey.

The officers elected for the coming year were as follows:

J. E. Holst, Mitchell, *President*
W. P. Wells, Aberdeen, *Vice-President*
W. W. Towne, Pierre, *Secretary-Treasurer*
S. W. Swanson, Rapid City, *Director*
H. J. Steckler, Yankton, *Director*
E. R. S. McGillicuddy, Elk Point, *Director*
M. T. Wyatt, Pine Ridge, *Director*
B. Percy, Winner, *Director*
B. A. Nangle, Belle Fourche, *Director*
G. J. Gunderson, Madison, *Director*

W. W. Towne, *Secretary*

GEORGIA WATER AND SEWAGE ASSOCIATION

Ninth Annual Meeting

Atlanta, Georgia, October 16–19, 1940

The ninth annual Georgia Water and Sewage School was concurrent with the annual meeting of the Georgia Water and Sewage Association. The evening business meeting and banquet provided the occasion for transacting the business affairs and electing officers of the Association. It was also the fun spot of the School enlivened by toasting, roasting and dining.

Clark W. Jones, Dalton, President of the Association, presided at the dinner and Paul Weir, Atlanta, Secretary, served as toastmaster. The following were recipients of awards for meritorious service or outstanding accomplishments in the water works and sewerage field during the year. W. L. Huckeba, Superintendent of Filtration, Carrollton, and R. T. Littlefield, Superintendent of Water Works, Jesup, received certificates of award for outstanding operation of local plants and systems. These awards carry subscriptions to a water works periodical. J. S. Harris, Operator, Atlanta Filtration Plant, received the Frederick J. MacMullin Memorial Award carrying affiliate membership in the American Water Works Association for service in preparing issues of "Drippings from the Georgia Faucet." Honorary life membership in the Georgia Water and Sewage Association was conferred on H. A. Wyckoff, Biology and Public Health Engineering Departments, Georgia School of Technology.

Officers elected by the Georgia Water and Sewage Association were: George H. Sparks, East Point, *President;* H. E. Whelchel, College Park, *First Vice-President;* W. H. Weaver, Decatur, *Second Vice-President,* and Paul Weir, Atlanta, *Secretary-Treasurer.* Directors elected on the

Board of the Federation of Sewage Works Associations were Porter Enloe and G. R. Frith of Atlanta.

The total attendance at the school was 343, exceeding that of any previous year, and comprised 307 superintendents, operators, municipal and other public and industrial officials and 36 manufacturers representatives. The large registration evidenced the important place that the School occupies in the Georgia plan of providing the instructive stimulus for efficient operation of water and sewage plants and swimming pools. The School also permitted representatives of communities not yet adequately provided with modern facilities to gain practical ideas for planning local water and sewerage programs.

The School, sponsored and conducted jointly by the Georgia Water and Sewage Association, the Georgia School of Technology, and the Georgia Department of Public Health, was held in the classrooms of the Georgia School of Technology. The instruction schedule was planned by a committee representing the three sponsoring agencies. Instructors were supplied by these organizations supplemented by qualified persons selected from allied professional fields. Instruction was conducted by the lecture-demonstration method to which was added informal discussion and plant inspections.

Sewage plant operation and swimming pool maintenance were given increased emphasis in the instruction schedule. The similarity of principles involved made it possible to combine discussion of these with water purification subjects thus effecting a considerable saving of time and eliminating duplication in teaching effort. A special class was conducted for those attending for the first time. During this separate session principles basic to both water purification and sewage treatment were explained. This procedure enabled the men in this group to adjust themselves more readily to the subjects under study by the advanced group.

Field Inspection Tour.—One day was spent in visiting cities in the northwest portion of Georgia. A motorcade of over sixty automobiles transported those attending the School to Marietta, Rome, Berry School, and Cedartown for inspection of interesting plants on a one hundred fifty mile trip, returning in the evening to Atlanta.

The first stop was at Marietta to inspect the new West Side sewage treatment plant and the municipal swimming pool. Stopping next at the Tubize Chatillon Corporation, the preparation of water for rayon manufacture was observed. An interesting part of this plant inspection was the opportunity to see the careful laboratory control and system of record keeping involved in the production of a high grade industrial water from the turbid Oostanaula River.

The motorcade arriving in Rome at noon was greeted by representatives of the Chamber of Commerce and the City Commission. These two bodies were hosts at a barbecue served to the group in the municipal pavilion overlooking the city and the industrial vicinity.

Following lunch the motorcade continued on to the recently com-

pleted Rome water plant. Leaving the Rome plant the motorcade separated into two sections, one going to the Berry School campus for further water plant inspection and the other to Cedartown for sewage treatment plant operation observation. The group which visited Cedartown inspected the new sewage plant to observe the treatment of textile dye wastes combined with domestic sewage. While this was the longest and most extensive inspection trip over undertaken by the Georgia Water and Sewage School there was unanimity of opinion that the day was most profitably spent in visiting this group of new plants in the progressive cities of industrial northwest Georgia.

PAUL WEIR, *Secretary*

Reviews and Abstracts

MODERN SANITATION IN GREAT BRITAIN

By D. M. Watson

J. Inst. C. E., 13, 125–146 (Dec., 1939)

This is a paper prepared by Watson for the British-American Engineering Congress at New York in September, 1939. After commenting on the central administrative control of design current in Great Britain, Watson discusses the handling of surface water. British practice provides for the discharge to the treatment works of six times the dry weather flow. Surface water, even from separate systems, may be polluted. The tendency is towards the coordination of adjoining drainage systems. The practice of handling industrial wastes has changed under the recent Public Health (Drainage of Trade Premises) Act, 1937, in that the manufacturer now notifies the authority that he desires to discharge wastes into the sewers. The authority then may fix the conditions, such as preliminary treatment, special payment, limit of maximum rate of discharge, uniformity of discharge, and set up limits of temperature, strength, suspended matter, etc. The manufacturer may appeal to the Ministry of Health or treat his own wastes.

Changes in manufacturing methods have reduced wastes, as in the beet sugar industry, or in the milk industry.

Possible contamination of ground water used for water supply has led to elaborate precautions in sewage treatment works to prevent percolation through soil or fissured chalk.

In sea outfalls, the tendency is toward settling the sewage. Complete purification is unknown.

The mechanization of sewage works has advanced and is lessening the difference between American and English practice. Hand cleaning of tanks is disappearing.

The handling of screenings is in a state of flux, burial being common, or handling as sludge. The old-time detritus pit is being supplanted by more modern grit chambers to separate heavy mineral grit from light organic matter.

Pre-treatment of sewage prior to settlement is in its infancy. Pre-aeration ahead of activated sludge may be helpful, perhaps between two stages of pre-sedimentation, as at Coleshill.

The tendency in Great Britain is to reduce the size of settling tanks, where formerly ten to fifteen hours were considered necessary. Flexibility of control has resulted in two-stage sedimentation.

Activated sludge treatment is growing in favor. Of the mechanical aeration devices, the Simplex, Sheffield, and Hartley systems have survived. Probably the diffused air and the Simplex method are most popular. Return sludge up to 50 per cent of the dry weather flow and return of purified effluent up to 50 per cent of the dry weather flow are being tried.

Partial purification by activated sludge has proven successful in increasing the efficiency of old trickling filters.

Trickling filters are still in favor for many situations.

Cleaning of sludge drying beds is still almost wholly by hand. Sludge drying works may be apart from the sewage treatment works.

Digestion followed by vacuum filtration and incineration are under consideration. Unique to Great Britain is the Porteous system of cooking sludge at 360° F. for 30 minutes, settling, pressing sludge to cake, and burning the cake. This is on trial on a scheme handling 14,000 population. Collection of gas from digestion is rare. On the smaller schemes, open sludge digestion lagoons with earth banks are often used.

Storm water tanks are usually of a capacity for six hours of the dry weather flow,

but occasionally larger. Under modern practice the tanks are gradually unloaded into the treatment plant, instead of decanting direct to the river.

LANGDON PEARSE

THE HYDRAULIC PROBLEM CONCERNING THE DESIGN OF SEWAGE STORAGE TANKS AND SEA-OUTFALLS

BY J. R. DAYMOND

J. Inst. C. E., 13, 217–236 (Jan., 1940)

This is a mathematical discussion of the hydraulic problem of discharging a storage tank through an outfall, assuming the rate of inflow into the tank is constant, the area of the tank is constant, the discharge is permissible at all stages of tide and the end of the outfall, provided with a tide-flap gate, is below low-water level at all times. The problem was dealt with experimentally on a model.

LANGDON PEARSE

THE DETERIORATION OF CONCRETE IN CONTACT WITH SEWAGE

BY S. S. MORRIS

J. Inst. C. E., 13, 337–342 (Feb., 1940)

This paper relates to conditions in Capetown, South Africa, where deterioration of concrete in contact with sewage has been marked. A yellowish-white flaky coating forms on the concrete surface, which gradually breaks down. Two different bacteriological processes are involved: (1) the formation of H_2S, (2) the oxidation of H_2S to H_2SO_4.

Hydrogen sulfide may be formed by either the reduction of mineral sulfates by organisms like *Spirrilum desulphuricans* or by the splitting up of the three sulfur-containing amino acids (cystine, cysteine, and glutatheone) by a variety of saprophytic microorganisms, found in sewage becoming septic.

Hydrogen sulfide is then absorbed by the true sulfur bacteria, which oxidize it to sulfur and store it in the bacterial cell, to be excreted and oxidized either to sulfuric acid or sulfates.

To prevent the corrosion of concrete, it is desirable to avoid the formation of septic sewage. Preventive measures are adequate ventilation, completely filled system, chemical treatment, and cast-iron mains as far as possible.

Experiments at Capetown with plaster of Cape Portland cement, ferrocrete and Ciment Fondu showed that wire brushing the surface was sufficient before repair and that Ciment Fondu was the most resistant. The tests lasted about 3 2/3 years.

LANGDON PEARSE

THE INFLUENCE OF OXYGEN CONTENT ON THE BIOCHEMICAL OXYGEN DEMAND, SELF-PURIFICATION OF WATER AND ACTIVATED SLUDGE

BY KARL VIEHL

Zeitschrift L. Hygiene und Infektions krankheiten, 122, 35 (1940)

I. *The Influence of Dissolved Oxygen on the B.O.D. and on the Natural Self-purification of Water.*—The initial dissolved oxygen values of stream water were adjusted by

means of nitrogen and oxygen gases to various concentrations covering a range from 1.66 to 41.0 p.p.m. of initial dissolved oxygen. Seven tests were made covering the range from 1.66 to 11 p.p.m. initial dissolved oxygen. The individual as well as the average values show an increase in B.O.D. with increasing initial dissolved oxygen. The difference in the oxygen uptake varied from 0.38 to 0.71 p.p.m. corresponding to an increase of 13–35 per cent of B.O.D. between the lowest and highest initial dissolved oxygen values. The increase in oxygen uptake within this range of dissolved oxygen values was fairly regular. A correction was introduced equivalent to the loss of oxygen by diffusion through the stopper for each corresponding initial dissolved oxygen value.

The second series of experiments consisting of four different tests covered a range of initial D.O. values from 6.54 to 41.0. Determination of nitrate content for the corresponding initial D.O. concentrations were made and the oxygen utilized for nitrification deducted from the total oxygen uptake. The correction for the loss of oxygen through the stopper for corresponding D.O. tensions was also made. The results showed that the oxygen uptake increased up to an initial D.O. concentration of 12.8 to 14.9 p.p.m. With higher initial D.O. tensions the oxygen uptake decreased. Nitrite formation also attained a maximum at about 15 p.p.m. D.O. tension. With higher D.O. tensions nitrite formation decreased and beyond 30 p.p.m. it was negligible. There was no nitrate formation. The average values indicate that there was a difference of 1.3 p.p.m. or 27 per cent in B.O.D. between the maximum value attained at 12.9 p.p.m. D.O. and the minimum value at 39.1 p.p.m. dissolved oxygen.

By putting the results of the two series together a curve is obtained for the entire range which shows increasing values of B.O.D. with increasing D.O. values from 2 to 12.9 p.p.m. B.O.D. values decrease with increasing D.O. tension beyond this maximum up to 40 p.p.m. D.O. By taking the values of the highest B.O.D. as a 100 per cent the values with 2 p.p.m. D.O. are 82 per cent and those at 40 p.p.m. D.O. are 73 per cent.

The author considers the oxygen content of the water as another factor counterbalancing the influence of temperature on the aerobic decomposition process. Thus the dissolved oxygen factor would tend to increase the self-purification process in the winter counterbalancing to some extent the effect of the lower temperature.

For the B.O.D. determination these studies have the following bearing:

(1) In the direct method where pure oxygen is used the values are apt to be lower than when air is used.

(2) The dissolved oxygen content should not be below 2.0 p.p.m. otherwise the variations would be too great.

(3) The influence of dissolved oxygen on the oxygen consumption is not great so that it is possible to obtain comparable results by using a definite average dissolved oxygen content. (*Abstractor's note:* In the dilution method it is possible to start with a definite average D.O. value, but oxygen consumption proceeds against a constantly decreasing dissolved oxygen value.)

In spite of the influence of higher dissolved oxygen tension in increasing the B.O.D., dilution itself has the opposite tendency of lowering the B.O.D.

II. *The Influence of the Rate of Aeration on the Activated Sludge Process.*—Four aeration tanks were operated under laboratory conditions with continuous application of sewage to activated sludge under otherwise identical conditions, except for the rate of air application which was according to the following relative rates—Tank No. 1 = 1, Tank No. 2 = 2, Tank No. 3 = 4, Tank No. 4 = 12. The slowest rate of air application was sufficient to prevent the deposition of sludge.

The average results of operation for a period of four months were as follows: Table I.

Purification was adversely affected in tank No. 1 with a D.O. of 0.8 p.p.m. The sludge from this tank filtered slower than the sludge produced with higher rates of aeration. The moisture content of the sludge after 1 hour settling, however, was not higher than with the higher rates of aeration. The rate of aeration in tank No. 4 was somewhat high as is indicated by the higher turbidity due to the breakdown of the sludge, than with the next lower rate of aeration. H_2S was present even with the highest rate of aeration. Microscopic examination revealed that the number of types of organisms

TABLE I.—*D.O. Reduction*

	Avg.	Min.	Max.	B.O.D. %	Ox. Cons. %	NO_2	NO_3	Bacteria in Eff. ×1000 per c.c.	Turbidity m.m.	H_2S p.p.m.
Tank 1...	0.8	0.5	1.2	77	44	0	0	1513	88	31
Tank 2...	1.4	0.7	2.1	91	56	0.4	0.15	602	223	14
Tank 3...	5.2	4.0	6.4	90	60	7.1	11.7	455	254	6
Tank 4...	5.4	4.3	6.3	91	60	6.4	16.0	462	209	8

present in the sludge was lowest in tank No. 1. It contained an abundance of *Mastigophora*. Of the ciliates only Vorticella were present in large numbers. The relative abundance of *Sphaerotilus* and Zooglea (not counted) did not show an appreciable influence.

From these results the author concludes that for the activated sludge process 1.5 p.p.m. D.O. is sufficient. With higher D.O. contents the removal of organic matter is only slighly faster. The influence of D.O. seems of lesser importance in the activated sludge than in the natural self-purification.

H. HEUKELEKIAN

INVESTIGATIONS ON PERCOLATING FILTERS, III

BY H. WILSON AND E. J. HAMLIN

Proc. Institute of Sewage Purification, Part I, 39–40 (1939)

In the earlier work it was shown that during the winter the pilot enclosed and ventilated filter at one of the plants at Johannesburg, South Africa, treated 140 gallons of sewage per cubic yard of filter media per day, giving 75.9 per cent purification, while the open filter treated only 33.8 gallons per cubic yard with an equal purification. In the summer months the output of the two filters was almost equal. In order to determine whether the difference in the performance of these two filters in summer and winter was due to the temperature, the sewage was heated to approximately 80° F. and fed to the open filter during the winter. The results showed that heating of the sewage enabled the open filter to treat approximately the same amount in cold months as was possible in the warmer months of the year.

A 3 ft. diameter model open filter with 5 feet of ¾ in.–1¾ in. stone and 1 foot of 3 in.–4 in. stone at the bottom was operated at high rates with the following results:

Gallons/Cu. Yd.	Per Cent Purification
690	57.8
1018	41.8
1575	39.7
1750	30.4
1980	23.0

The authors believe that high rate application during the winter months results in preventing the temperature drop and consequent slowing down of purification.

A thorough study was made on the effect of different temperatures on the performance of the filters. For this purpose eight twelve-inch diameter steel tubes surrounded by heated water jackets were used. The media consisted of 1 ft. of three-inch stone at the bottom and 4½ ft. one-inch stone on top. The range of temperature studied was from 70° F. to 120° F. Purification was measured by oxygen absorbed in 4 hours and also by nitrification. Up to 95° F. an improvement was obtained by increased tem-

perature but at 100° F. both purification and nitrification seriously diminished. These results were obtained with equal rates of application to each filter. In a subsequent run a reduction of the dose to the filters operating at 100° F. and above, resulted in improved effluents. Five days after the temperature of the filter, operated at 120°, was dropped to 85° F. nitrification started. It is concluded that nitrifying organisms were not killed at the higher temperature.

The effect of introduction of carbon dioxide into the filter was studied. The results showed that although high concentrations of carbon dioxide (5–10%) are deleterious, the concentration such as can ordinarily be found in the beds is not harmful. Therefore, ventilation of a filter for the purpose of sweeping out carbon dioxide is unnecessary.

In discussing the economics of covering of a filter the dome roof type is considered too costly. Two patented types of a lighter form of construction are considered, (1) shell type consisting of thin reinforced concrete membrane spherical in shape and (2) diagrid system of construction consisting of light square concrete slabs supported on a grid of concrete beams which are continuous in all directions. Cost estimates are prepared for the open versus these two types of covers for a filter six and twelve feet deep and of different diameters. The following conclusions are drawn from the comparative cost estimates of six foot filters:

(1) In the open type of filter the cost per unit volume of sewage decreases as the diameter of the bed increases but little advantage is to be gained by units of a larger size than 100 ft. diameter unless the size of the plant is very large.

(2) In covered filters the most economical size is about 80–100 ft. diameter. Also a covered filter provided it will treat 1¾ to 2 times the quantity of sewage as in the open filter, will prove more economical.

For the local condition the covering of a filter merely for heat conservation was considered justified. An additional advantage of the enclosed filter is the control of odors. It may also serve as a method of control of filter flies.

H. HEUKELEKIAN

OHIO CONFERENCE ON SEWAGE TREATMENT
THIRTEENTH ANNUAL REPORT

Activated Sludge Control. By J. R. Palmer, pp. 11–21. Discussion by Dwight Bender. This paper is a discussion of activated sludge control together with specific references to control practice at the North Side sewage treatment works of the Chicago Sanitary District. In the latter connection a description of the plant is given, which includes three photographs, a general plan of the plant and a channel and sewer layout.

The variables to be considered in activated sludge plant operation are given as: (1) concentration of solids in the mixed liquor, (2) quantity of air used, (3) aeration period, (4) settling period, and (5) rate of sludge return.

Efficient air use requires the lowest concentration of solids in the mixed liquor consistent with satisfactory operation. North Side plant experience indicates that an average solids concentration of 2300 p.p.m. is required to give good results. Mixed liquor solids concentration is controlled by wasting excess sludge. The desirability of flexible sludge wasting facilities is noted.

Economically, the most important variable is the amount of air used. Present aeration practice is to use sufficient air to obtain good clarification with a minimum of nitrate production. At the North Side plant the oxygen concentration in the mixed liquor is determined on samples collected every four hours at six points in the aeration tanks. Two c.c. of 10 per cent copper sulfate solution are added to a wide mouth quart bottle which is then dipped carefully into the mixed liquor. The copper sulphate coagulates the sludge and stops biological activity. The copper concentration in the supernatant is too low to interfere with the dissolved oxygen determination, which is run after the clarified

sample has been siphoned into a smaller bottle. Instead of the usual sodium thiosulphate titration as the final step in the dissolved oxygen determination a colorimetric method involving comparison of the sample with iodine solution standards is used. North Side plant operating experience has indicated the desirability of maintaining a small amount of dissolved oxygen at the head of the aeration tanks with a gradual increase up to about 2 p.p.m. at the end. Concentrations as low as 0.5 to 1.0 p.p.m. at the end have not proved sufficient.

The North Side plant sludge return rate is based partially on the practice of avoiding a deep sludge blanket in the final tanks. With deep blankets the sludge tends to become septic and operation is more difficult. Rate of sludge return is increased as the sludge index rises. Use of a series of small air lifts whose intakes are staggered in elevation in the final tank has been found a very satisfactory means of final tank sludge depth control. These air lifts operate continuously and observation of the discharges indicates the depth of the sludge.

In discussing sludge activity the author states that it is generally accepted that the first function of activated sludge is the removal of colloidal matter by adsorption after which the floc surfaces must be reactivated by subsequent aeration. The idea of expressing the activity in terms of the adsorptive properties of the sludge has been considered. In this connection the adsorption of ammonia has been studied.

Bulking of activated sludge is considered to result from: (1) filamentous growths, (2) underaeration, (3) low ash content. Bulking due to filamentous growths (*Sphaerotilus*) occurred at the Maywood plant (cf. THIS JOURNAL, **1**, 46, 1928). The difficulty was traced to the presence of carbohydrate wastes. Tests indicated over 1 ton of dextrose per million gallons. Diversion of these wastes corrected the bulking problem. Bulking caused by underaeration is indicated by a sludge which is light gray in color and which has lost the normal flocculent appearance. Final tanks have a turbid milky appearance.

The common cause of bulking at the North Side plant is lack of inorganic matter in the sludge. This condition ensues during periods of prolonged drought. Under these conditions the sludge has about the same characteristics as normal sludge except that it is not as dense. The relationship of ash content, sludge index and annual rainfall is shown graphically. Following a series of heavy rains the ash content increased from 30 per cent to over 50 per cent corresponding to a decrease in sludge index from 75 to 25. From 1936–38 sludge at the Calumet plant had an average index of 44 with an ash content of 46.5 per cent. During the same period at the North Side plant the average sludge index was 73 with an ash content of 31.8 per cent. The greater amount of ash at the Calumet plant is mainly due to industrial wastes. Increasing the ash concentration by adding fly ash, clays, etc., has indicated some beneficial effect on an experimental scale.

Air used at the North Side plant in the period 1934–38 ranged from 0.35 to 0.38 cu. ft. per gallon; suspended solids removal from 89.8 to 93.0 per cent. Raw sewage suspended solids averaged 140 p.p.m. Five day B.O.D. removal ranged from 88.4 to 92.2 per cent with raw B.O.D averaging 112 p.p.m. Sewage flow averaged 200.5 M.G.D.; sludge index, 69.

The discussion confines itself mainly to a consideration of activated sludge control at Indianapolis, Indiana, by means of a "biometer" an instrument for measuring sludge oxygen demand and activity in terms of the rate of oxygen consumption in p.p.m. per hour. Two graphs bearing on the rate of oxygen demand and included and interpreted in relation to plant operation. The results of oxygen demand rate studies indicate that the rate at which the organisms responsible for the demand work varies considerably during the aeration period. This is indicated by the fact that at the beginning of aeration the rate of oxygen consumption is between three and four times that at the end.

The author concludes that oxygen consumption determinations are an important asset to intelligent plant control.

The Ohio River Pollution Survey—Methods and Progress. By H. W. Streeter and E. S. Tisdale, pp. 26–45.—The Ohio River Basin pollution survey was undertaken in accordance with a provision of the River and Harbors Act of 1937 which directed the Secretary of War to make a survey of the Ohio River and its tributaries, in order to de-

termine sources and amounts of pollution and practical methods of their elimination or correction. The Act also provided for the preparation of a comprehensive report to Congress with recommendations for remedial legislation. The task of collecting data as to sources and amounts of pollution, laboratory data on water quality and other information relative to pollution, was assigned to the U. S. Public Health Service. The Corps of Engineers, U. S. Army, are making hydrometric studies and are collecting all hydrometric data necessary in connection with the pollution survey. Epidemiological studies of water-borne diseases are being carried on as a special activity by the Public Health Service. Coordinated direction is provided by the Ohio River Board consisting of a representative of the Public Health Service, the Corps of Engineers, and the National Resources Committee. An organization chart indicating cooperating agencies and personnel is given.

The organization for field surveys is based on cooperation with the health departments of the various states in the basin. This arrangement allows the rapid and economical assembly of information on public water supplies, sewage disposal, industrial wastes and the effect of such wastes on various water uses.

In connection with the investigation of industrial wastes, guides covering industries operating in the Ohio Basin have been prepared. These guides give information about quantity, quality, population equivalent and best known methods of treatment of various types of waste.

Laboratory surveys were founded on the use of two base laboratories with cooperating mobile units operating in the field. One base laboratory was established at Cincinnati; the other on the large quarter boat "Kiski," which is moved to various convenient points along the Ohio River. Mobile units consist of conventional automobile trailers equipped as laboratories and tow cars.

Routine laboratory determinations include temperature, turbidity, pH, alkalinity, total and volatile suspended matter, 24 hour plate count at 37° C., coliform bacterial enumerations (most probable numbers by fermentation tests and direct count by brilliant green lactose plates) dissolved oxygen and 5-day B.O.D. Comparative results thus far obtained indicate that fairly accurate coliform enumerations can be obtained by the direct plating method in skilled hands but development of the necessary skill requires at least two months intensive work with the method.

Laboratory data or coliform numbers, dissolved oxygen, and B.O.D. plotted against river miles for the reach from Point Pleasant to below Cincinnati for both high and low flow conditions are presented graphically and interpreted.

Five maps of the Ohio Basin, indicating sampling stations, progress as of September, 1939, and coliform numbers and dissolved oxygen at various stations, are also included in this report.

It is concluded that when the data collected are assembled and analyzed, they will provide the foundation for a comprehensive engineering plan of stream sanitation for the entire Ohio River watershed.

Discussion of Civil Service. By George E. Barnes, pp. 46–49.—Civil service regulations are operative in the federal government and in fourteen states. The Ohio constitution provides for civil service in the various state, county and city departments.

The effectiveness of civil service is related to the following considerations (1) the form and content of the law and regulations, (2) the administration of the laws, (3) the status of employees in various branches of service as compared to that of others in similar positions in public service or industry.

The remainder of the paper is devoted to consideration to the Ohio civil service law and its administration and a suggestion as to the formation of a committee to confer and report on civil service in the light of the experience of the waterworks and sewage treatment plant operators.

Administration of Sewage Works.—By F. O. Wallene, pp. 41–49.—Cleveland has recently finished three new sewage treatment plants representing a 20 million dollar investment. Funds for operation are obtained from an extra charge of 40 per cent on

the water bills collected. This approximates $0.32 per 1000 cu. ft. Charges are made only to those water consumers contributing sewage to the plants. Premises in unsewered areas or whose sewage is untreated cannot legally be charged for plant operation. The legal department has held that this is a utility service and that charges must be based on the proportion of services rendered. This plan is practicable and equitable in Cleveland since the city is 100 per cent metered. Interest and debt retirement charges are met by real estate taxes. Therefore, owners of vacant property contribute to the payment of fixed charges but not operating expenses.

Recently, however, legislation was enacted cutting the payment to 25 per cent and providing for a repeal date of this plan early in 1940. This suggests that future charges may be on the basis of real estate taxes.

All Cleveland sewage department employees are under civil service and this has made possible the operation of the department on a business-like basis with good employee morale.

The author considers that the big problem in sewage plant management is not that of personnel or actual operation but one of education of the public to the service the plant is rendering to each individual.

In closing the author states that lack of inadequate funds seriously interferes with proper operation and that every operator has a definite responsibility in educating administrative officials and the public as to the importance of careful operation of a sewerage system.

A Study of Milk Waste Treatment. By B. F. Hatch and J. H. Bass, pp. 50–91.—This comprehensive report represents a substantial contribution to the literature on the treatment of the milk industry's wastes and the data resulting from the large scale studies made should be of value to the milk processing industry, sewage plant operating personnel, engineers, public health officials and others interested in industrial waste treatment problems.

The study, which relates to the operating performance of three actual milk waste treatment installations, was authorized by the Ohio Department of Health upon recommendation of the sanitary engineering division. Supplementary to plant operating data, results as to the nature and quantity of milk wastes from milk processing plants were obtained. Cooperation to the extent of defraying certain costs of the study was obtained from the milk companies and other interested individuals.

The treatment plants studied are designated as. Coldwater, Glen Karn and New Bremen, according to the municipality near which each is located.

The Coldwater milk-processing plant is equipped to handle a whole milk intake of 300,000 pounds per day. The principal product is canned evaporated milk. The waste treatment plant, built in 1937, consists of a primary settling tank, excess raw waste storage basin, settled waste pumps, trickling filter, secondary settling tank and operating building. The plant receives, in addition to wastes from floor and equipment wash, the sludge from a lime-soda boiler water softener, draw-off from the condensing water recirculating system and ordinary sewage from the plant. Primary and secondary sludge are pumped to a tank truck and hauled to an adjacent farm for land disposal. Plant effluent discharges to a small wet weather tributary of the Ohio River.

The Glen Karn processing plant is equipped for a daily whole milk intake of 80,000 pounds. The principal product is American cream cheese. Wastes consist of floor and equipment wash and whey. The whey is pumped to two outside storage tanks from which it is hauled by truck to another plant for processing. If the capacity of these tanks is exceeded a small amount of whey may be discharged to the waste treatment works. The treatment plant, built in 1936, employs the Guggenheim treatment process and consists of a stationary fine screen, two interconnected raw waste storage tanks, a raw waste pump, two blowers, chemical feed devices, flash mixing chamber, aeration basin, final settling tank and operating building. The plant operates continuously at 1000 gallons per hour; and when there is no raw waste, plant effluent is returned to the first stage tank. Operation involves agitation of raw waste in the primary storage basin with air, followed by discharge at a constant rate from this tank to the flash mixer where a lime slurry, iron

salt solution and return sludge from the final settling tank are mixed by air. The next unit is a four compartment aeration basin having a detention time of four hours. The effluent from the aeration basin flows to a hopper bottom, final settling tank having a detention period of two hours. Blowers have capacities of 20 and 50 cubic feet per minute. Waste sludge is discharged to two lagoons each 40 ft. square in plan with a depth of 10 ft. Plant effluent discharges to a small stream having a dry weather flow of less than 0.5 c.f.s.

The New Bremen plant manufactures butter, condensed milk, milk powder, ice cream, ice cream mix and semi-solid buttermilk. About four million pounds of butter are manufactured each year. The waste treatment works was constructed in 1935 and employs activated sludge treatment. The plant consists of a chemical mixing tank where lime is added for pH correction, ridge-and-furrow type aeration tank (detention time, 24 hours at 55,000 g.p.d.), hopper bottom final settling tank and operating building. Excess sludge is hauled by tank truck to adjacent farms for disposal by spreading on the soil. Enough lime is used to maintain a pH value of 8.0. Sufficient air is supplied to the aeration tank to maintain dissolved oxygen in the plant effluent. The blowers, which ordinarily operate simultaneously, have capacities of 95 and 168 cubic feet per minute. The plant effluent discharges to a ditch which has no dry weather flow except the effluent.

Samples from these three plants were collected at one half to one hour intervals and composited according to flow at each treatment plant. Sampling periods extended over 24 hours except at Glen Karn where it averaged 13.5 hours. Sludge samples were collected daily and composited into weekly samples. Analytical and flow data for each plant and loadings computed from these data are summarized, together with actual operating data, in 28 tables and indicated graphically by six charts. Photographs of the plants are included.

The milk solids loading, for which each of the treatment works was designed, was based on a 2 per cent loss of the manufacturing plant's milk solids intake. Values for the ratio of pounds of milk solids to pounds 5-day B.O.D. are given as 1:1 to 1:1.1. It is considered hazardous to design on any basis other than that of per cent loss of milk solids unless dependable data on concentration and volume of milk wastes collected over a considerable time period are available. Hourly, daily and even seasonal variations in volume and concentration are such that designs based on one day composite samples may be more than 100 per cent in error.

Daily Variations in Oxygen Loading

Treatment Works	Raw Waste 5 day B.O.D. Avg.	Max.	Min.
Coldwater	330 Lb.	580 Lb.	210 Lb.
Glen Karn	94.4	214	32
New Bremen	299.9	493	176.3

These data represent daily variations and do not indicate full effect of hourly or seasonal variations.

Average Treatment Works Daily Loading Data

Location	Volume G.P.D.	5 day B.O.D.		Milk Solids			Pop. Equiv. per 1000 lb. milk Solids Intake
		p.p.m.	Lb.	Intake Lb.	Loss Lb.	% Loss	
Coldwater	30,800	1,291	330	19,060	300	1.57	108
Glen Karn	15,570	755	94.4	3,698	86	2.32	159
New Bremen	29,700	1,246	299.9	15,880	273	1.72	118

Composition of Whole Milk, Skim Milk, Whey and Buttermilk†

	Whole Milk	Skim Milk	Whey	Buttermilk
Water	87.4%	90.25%	93.19%	90.78%
Fat, R–G	3.75	0.78	0.04	0.69
Total Solids	12.60	9.75	6.81	9.22
Non-fat Solids	8.85	8.97	6.77	8.53
Milk Solids *	11.90	9.02	6.06	8.49
Ash	0.70	0.73	0.75	0.73
Protein	3.29	3.41	0.97	3.29
Lactose	5.14	5.21	4.37	3.71
Five day B.O.D. (*1% solutions*)	1184 p.p.m.	818 p.p.m.	433 p.p.m.	852 p.p.m.

* Total solids less ash.

† Determined in 1930, Ohio Dept. Health.

Composition of Raw Milk Wastes

Location	5 Day B.O.D. Pounds	Total Susp. Solids-Lb.	Population Equivalent Based On	
			B.O.D.	Susp. Solids
Coldwater	330	192.5	2060	1600
Glen Karn	94.4	46.1	590	385
New Bremen	299.9	158.5	1870	1320

Primary Settling Tank Performance

	Suspended Solids			B.O.D.		
	Raw Lb.	Settled Lb.	% Red	Raw Lb.	Settled Lb.	% Red
Coldwater	192.5	103.0 *	46.4 *	330	153.3 *	53.5 *
New Bremen	158.5	57.7	63.6	299.9	154.0	48.6

* Corrected for dilution water (see plant description).

Common design practice has been to place most of the organic loading on the secondary devices. These data indicate that this practice is questionable.

Overall Average Solids and B.O.D. Reductions

Location	Per Cent Reduction Total Suspended Solids	Per Cent Reduction 5 Day B.O.D.
Coldwater	93.4	98.2
Glen Karn	66.0	76.2
New Bremen	96.1	98.9

(Reductions based on flow discharged to receiving stream)

Low volatile content and high pH of primary sludge at Coldwater and New Bremen are attributed to presence of lime-soda sludge and use of lime.

Sludge disposal methods appear to be satisfactory as no complaints have been received.

Summary of Results of Analyses of Sludge

		Coldwater		Glen Karn	New Bremen	
		Raw	Secondary	Secondary	Raw	Secondary
Solids:	Total	4.68%	2.80%	0.64%	5.59%	0.85%
	Volatile	1.52%	1.67%	0.32%	2.66%	0.57%
Nitrogen:	* Free NH_3	64 p.p.m.	52 p.p.m.	3.5 p.p.m.	81 p.p.m.	28 p.p.m.
	Organic	544	891	142	1165	517
	Total	608	943	145.5	1246	545
Alkalinity:	M.O.	1182	1233	405	1413	310
	pH	8.9	7.3	6.4	8.2	6.4

* Nitrite and nitrate reported zero in each case.

Operating Costs

(Power at 1.5 ¢ per kilowatt-hour. Depreciation and interest charges assumed 10% original cost.)

	Coldwater, Cost/Day	Glen Karn, Cost/Day	New Bremen, Cost/Day
Labor	$ 4.03	$ .70	$ 4.05
Power	.98	.92	4.07
Chemicals	—	1.77	1.43
Maintenance	.20	.07	.20
Depreciation, Interest	7.91	1.45	4.11
Total per day	$13.12	$4.91	$13.86
Total per year	4788.90	1792.15	5058.90
Lb. B.O.D. removed/day	324.1	71.9	297.2
Cost/Lb. B.O.D. removed	$ .0405	$ .0683	$ .0466

Conclusions

Milk solids losses incidental to the manufacture of evaporated milk, butter and cheese may be expected to approach 2 per cent of the milk solids intake in pounds per day with ordinary plant housekeeping.

Daily fluctuations in both volume and concentration produce variations in oxygen loadings of approximately 100 per cent of the average.

Milk wastes in terms of equivalent population may be expected to have 25 per cent to 35 per cent less suspended solids in pounds per capita than domestic sewage.

(*Abstractor's note:* I do not think the above statement is very clear. The authors refer to Table 25 in original paper entitled "Composition of Raw Milk Wastes." Wouldn't it be better to state: "Population equivalent of milk wastes computed on a suspended solids basis is from 25 to 35 per cent less than that computed on the basis of B.O.D." ? I believe this is the way the computations for population equivalent were made in Table 25.)

Suspended solids may be reduced by plain sedimentation and a 50 per cent removal apparently causes a quite similar reduction in total oxygen demand.

The plain sedimentation-trickling filter method of treatment requires a higher capital investment than either of the other two. Operating cost of this type, considering all factors, is less than the cost of the other two on an oxygen demand reduction basis.

Trickling filters with applied load concentration controlled by dilution are better able

to withstand sudden fluctuations in raw waste characteristics than the other two treatment methods studied. Trickling filters are recommended for small plants.

The Guggenheim process is capable of producing a better effluent than is reflected by this study. To accomplish this, however, requires careful operation.

Excellent quality effluent may be obtained by the use of the activated sludge process but careful control is required.

There is apparently no possibility of designing a milk waste treatment works which will be entirely automatic in operation.

Flocculation of Sewage Without the Addition of Chemicals at Massillon. By R. F. Snyder, pp. 92–98.—The Massillon, Ohio, plant includes primary treatment or chemical precipitation and separate sludge digestion. Steel mill acid pickling wastes which are discharged to the city sewer system caused damage to the raw sewage pumps and during May, 1938, the average iron content of the raw sewage was 44 p.p.m. Laboratory work indicated that if the introduction of the steel mill wastes into the sewers could be controlled advantage could be taken of their presence for chemical precipitation. This control had not been accomplished at the time the plant scale flocculation study was conducted. The latter covered a period of one month during which the iron content of the sewage averaged 144 p.p.m. The results indicate in a general way that operation of the plant flocculator units without addition of chemicals save for 10 p.p.m. of lime during one week's run resulted in appreciably greater B.O.D. reduction due to flocculation of the iron. Average reduction in B.O.D. was 56 per cent. Comparable previous reduction was 46 per cent. Various flocculator speeds were tried. However, the period of operation was too short and conditions too variable to permit definite conclusions.

Final Tank Effluent as Used to Maintain Fish Life at Lima. By C. W. Prentice, pp. 99–101.—A fish pool supplied with effluent from the Lima, Ohio, activated sludge plant was constructed in 1938. The pool is supplied with effluent by means of a small pump driven by a novel bicycle water wheel operating in the effluent flume of the final tank. Gold fish, bass and other species thrive in the pool.

Sampling Final Tank Sludge at the Findlay Sewage Treatment Plant. By Robert W. Bowman, pp. 102–103.—Five one-inch sampling pipes were installed in the final tank of the Findlay, Ohio, activated sludge plant. The pipes extend into the final tank at the floor line, and at six inches, one foot, two feet and three feet above the bottom and run from the final tank to a nearby pipe gallery. Samples are collected near the end of each shift and this enables the incoming shift to determine the depth of the sludge blanket and pump off excess sludge as necessary.

The Safety Features of the Imhoff Tank Reconstruction at Dayton. By W. B. Nagel, pp. 104–106.—Protection against explosions at Dayton, Oio, may be divided into two phases; (1) precautions taken to eliminate all possible sources of explosion; and (2) precautions taken to protect the inclosing and surrounding structures from serious damage should an explosion occur.

Elimination of possible sources of explosion necessitates adequate reliefs, proper materials and the isolation of the gas collection system.

The type of construction used on the pipe gallery and relocation of adjacent structures is such that the effects of an explosion would be minimized. Should an explosion occur in the pipe gallery such as occurred in 1938 loosely fastened roof slabs will be displaced allowing the force of the explosion to vent itself without material damage to the conduits and Imhoff tanks. Little damage would be done to the piping as it is supported independently of the roof. Falling debris damage will be slight due to the small size of pieces that will be moved.

Details of gas collection equipment safety features are discussed.

Author concludes that safety practice may be summarized by saying: (1) isolate gas lines, (2) insulate sources of ignition, (3) investigate indications of leaks and, (4) insure the quick escape of gas accumulations.

Report of Committee on Corrosion. By Willard F. Schade, pp. 107–110.—Reference is made to the work of other groups in the field of corrosion and its prevention and to various articles published in recent years applying particularly to sewage works.

The following preliminary deductions were presented by the committee:

(1) Copper and certain copper alloys in many cases are not satisfactory especially in fly screens, gutters, skylights and floats. Stainless steel, aluminum, monel metal, galvanized metal, and bronzes are the answer to some of the problems.
(2) Cast iron and wrought iron are to be preferred to steel.
(3) Aluminum is generally satisfactory under mildly corrosive conditions and does not require continuous protection of the surface by painting as do ferrous metals. It has proven ineffective where exposed to small amounts of chlorine.
(4) Consideration is being given to the use of corrosion resistant materials for replacements.
(5) Cadmium plate deteriorates when exposed to moist hydrogen sulfide laden air.
(6) Ventilation is admitted as an aid in reducing corrosion.
(7) Coal-tar base paints and aluminum paint are most generally used. Painting is the principal method of combating corrosion but at best is not entirely satisfactory.

PAUL D. HANEY

THE BIOFILTRATION PROCESS OF SEWAGE TREATMENT

BY A. J. FISCHER AND R. B. THOMPSON

The Canadian Engineer, Water and Sewage, **78**, 16 (May, 1940)

The treatment of sewage by the biofiltration process involves the pre-settling of the sewage prior to its application to a trickling filter, and the recirculation of all or part of the filter discharge back to the detention tank. The purpose of the process is to reduce the size of the trickling filter required by increasing the dosing rate and B.O.D. loading and/or to provide a positive means of controlling the action of the clarifier-filter system so that more efficient operation under varying conditions can be obtained.

When sewage is repeatedly passed through a filter bed a uniform action takes place throughout the entire bed depth. Variations in the volume and strength of the applied material are reduced, while the net strength of the applied sewage in parts per million is decreased as the amount of recirculation is increased. Dosing rates are likewise increased, rates (including recirculation) of 125 m.g.a.d. being possible with 2 in. to 2½ in. stone. Usual rates are 20 to 60 m.g.a.d. These high rates cause continuous unloading of the biological film and assist in maintaining proper ventilation. The uniform action and the repeated passage of settled filter discharge allows the use of shallower bed depths.

With appropriate recirculated flow a B.O.D. reduction takes place in the detention tank, as the filter discharge is high in dissolved oxygen. Septic action in the detention tank is prevented.

Because of the relatively short period in the filter complete stabilization is not secured in the filter alone, as with standard low rate filters. This unit acts, rather, as a "colloider" and serves to coagulate partially by biological means, the collodial material in the sewage.

The biofiltration process was conceived by H. N. Jenks, a consulting engineer of Palo Alto, California. In 1936, a small commercial scale plant was put into operation at San Mateo, California, for treatment of part of the main plant flow for irrigation purposes.

There are three preferred flowsheets for carrying out the process, depending on the results desired. The single stage intermediate layout will give a degree of treatment, measured by reduction in the biochemical oxygen demand, between that obtained by the use of plain settling and by standard trickling filters. In this layout the influent is mixed with the filter effluent and passed to the detention tank, thence to the filter. Final effluent is drawn from the system between the detention tank and filter.

The single stage complete treatment plant will give results on a par with the standard trickling filter, B.O.D. reductions of 80–85 per cent being obtainable with 1:1 recirculation and with average strength sewage. Here the flow passes through the primary clarifier, filter and a final clarifier. The recirculated flow is made up of filter effluent and final clarifier effluent or underflow. It is added ahead of the primary clarifier.

The two-stage complete treatment layout utilizes two detention tanks and two filters. In the first stage raw sewage is mixed with filter effluent and passed to the detention tank, thence to the filter. The detention tank effluent passes to the second stage filter along with final clarifier recirculated effluent. This layout gives results comparable with activated sludge. With a recirculation of 1:1, 90–95 per cent B.O.D. reductions are obtainable.

The chief design features of the biofiltration process involve the use of shallow beds, the rating in terms of B.O.D. removal capacities, and the use of recirculation ratios. Clarifiers are rated on overflow rates as well as detention periods, and must be designed to handle the total influent, including recirculation.

Three foot depths of stone, 2 in. to 2½ in. have been used in single stage or primary filters, while the same depth of ¾ in. to ½ in. has been used for secondary filters in warm climates. For average conditions it is felt that 1 in. to 1½ in., or 1½ in. to 2 in. is better for secondary units. Good natural ventilation under the bed is essential.

Total dosing rates most commonly employed have been 20 to 60 m.g.a.d. with recirculation ratios ranging from one to three.

A table listing plants using the process is included in the paper. Seventeen installations are shown, ranging in size from 0.05 to 3.0 m.g.d. Of these eight are single stage, eight two-stage and one three-stage.

Operating results at the Petaluma, Cal., plant are shown. Here the two-stage complete treatment system is employed. The clarifiers are both 50 ft. in diameter and the filters are octagonal in plan, the short diameter being 75 ft. The depth of filter media is 3 ft. in both filters. Following is a condensed table of results covering seven tests.

	Two Stage					Single Stage	
Raw Dosing Rate, M.G.A.D.	5.22	5.00	5.05	6.10	10.6	4.90	4.96
Recirculation Ratio	5.82	2.90	2.40	5.90	2.50	2.50	0
Raw B.O.D. Loading, Lb./Cu. Yd./Day	2.47	2.69	2.47	3.25	4.78	5.35	6.53
Raw Sewage, p.p.m.							
Susp. Solids	420	394	424	447	462	437	472
B.O.D.	554	636	576	617	521	644	774
Primary Clarifier Effluent, p.p.m.							
Susp. Solids	175	126	124	221	150	167	181
B.O.D.	254	257	227	317	333	419	492
Final Effluent, p.p.m.							
Susp. Solids	85	38	33	104	43	48	91
B.O.D.	30	33	14	68	28	53	169
Per Cent Reduction							
Susp. Solids	79.9	90.3	92.3	76.8	90.7	89.0	80.7
B.O.D.	94.6	94.8	97.6	89.0	94.6	91.8	78.1

(1) B.O.D. loading based on volume of both filters. Loading on primary filter is twice figure shown.

Results at Healdsburg, California, are also shown. The plant is similar to the Petaluma plant, with 35 ft. diameter clarifiers and 36 ft. diameter filters with 3 ft. stone depth. Results are as follows.

Raw Dosing Rate, M.G.A.D.	8.02	7.90	8.20
Recirculation Ratio	5.10	5.19	0
Raw B.O.D. Loading, Lb./Cu. Yd./Day	1.99	2.53	2.79
Raw Sewage, p.p.m.			
Susp. Solids	200	249	210
B.O.D.	304	395	316
Primary Clarifier Effluent, p.p.m.			
Susp. Solids	69	64	114
B.O.D.	87	84	210
Final Effluent, p.p.m.			
Susp. Solids	27	29	56
B.O.D.	25	27	98
Per Cent Reduction			
Susp. Solids	86.5	88.2	73.4
B.O.D.	91.8	93.2	69.0

At Santa Mateo, California, a two-stage plant is used to treat part of the main plant flow. The settling tanks are 6 ft. by 15 ft. and the filters are 15 ft. diameter and 3 ft. deep. A condensed table of results is given below.

Raw Dosing Rate, M.G.A.D.	21.0	19.0	20.0	10.2
Recirculation Ratio	1.40	2.65	0	2.76
Raw B.O.D. Loading, Lb./Cu. Yd./Day	2.72	3.77	4.91	2.08
Raw Sewage, p.p.m.				
Susp. Solids	237	201	216	233
B.O.D.	151	231	286	238
Primary Clarifier Effluent, p.p.m.				
Susp. Solids	70	60	93	33
B.O.D.	72	45	76	16
Dissolved Oxygen	1.2	1.5	0	2.7
Final Effluent, p.p.m.				
Susp. Solids	23	17	32	30
B.O.D.	19	13	26	13
Dissolved Oxygen	4.3	3.8	2.7	5.2
Nitrites and Nitrates	2.3	3.6	5.6	9.9
Per Cent Reduction				
Susp. Solids	90.3	91.5	85.2	87.1
B.O.D.	87.3	94.3	90.8	94.6

Note that most of the work was done in the first stage, very little improvement being obtained in the second stage.

Tests on a small experimental single stage unit showed that the filter depth has but little effect on B.O.D. removal. A condensed table of results is shown below.

Filter Depth, Ft.	6	4	2
Dosing Rate, Raw, M.G.A.D.	12.0	12.0	12.0
Recirculation Ratio	4.0	4.0	4.0
Raw B.O.D. Loading, Lb./Cu. Yd./Day	2.4	4.15	8.45
Raw Sewage, p.p.m.			
Susp. Solids	315	293	288
B.O.D.	233	268	273
Primary Clarifier Effluent, p.p.m.			
Susp. Solids	160	133	147
B.O.D.	165	205	179
Final Clarifier Effluent, p.p.m.			
Susp. Solids	46	58	57
B.O.D.	63	52	67
Dissolved Oxygen	4.5	4.0	2.9

As regards economies of the process, figures are given on the installation costs of a few of the bio-filter plants. Detailed estimates are likewise given on the first cost and annual operating costs of a 1.33 m.g.d. plant for standard trickling filters, single-stage biofilters, activated sludge, and two-stage biofilters. These costs, exclusive of provisions for screening, grit removal, digestion, sludge disposal, buildings and landscaping, were as follows:

Standard Trickling Filter	$86,275 per m.g.
Single-stage Biofilter	43,505 per m.g.
Activated Sludge	49,730 per m.g.
Two-stage Biofilter	50,350 per m.g.

Estimated annual costs for that portion of the plant on which itemized costs are given are shown below. These figures include fixed charges at 7½ per cent.

Standard Trickling Filter	$7,560 per year
Single-stage Biofilter	5,110 per year
Activated Sludge	9,525 per year
Two-stage Biofilter	5,845 per year

It was concluded from numerous technical and economic comparisons that the bio-filter sould cost 30 per cent less than standard trickling filters, and cost 15 per cent to 20 per cent less to operate. Higher loadings and dosing rates and the 3 ft. filter beds are responsible for the lower first cost, while reduced fixed charges react favorably on the annual costs.

Filter fly and bed ponding nuisances are eliminated. The efficiency of the process may be controlled and high nitrification, relative stabilities and B.O.D. reductions obtained under all conditions, even where very strong sewage is encountered.

When compared to the activated sludge process it will be seen that the first cost is about the same but that operating costs, including fixed charges, are about 35% less for the biofiltration process. The biofiltration process, however, is not affected to the same degree as the activated sludge process by sudden fluctuations in the quantity and strength of sewage, and does not require the same high order of supervision to maintain top plant efficiency.

T. L. Herrick

TREND OF PRACTICE IN SEWAGE TREATMENT AND SLUDGE DISPOSAL AT RECENT LARGE PLANTS

By Almon L. Fales

The Canadian Engineer, Water and Sewage, **78**, 7 (May, 1940)

Only the largest sewage treatment plants have been included in this review, although there are numerous smaller plants which are of much significance. Some of the largest treatment plants, where the conditions are so unusual as not to be indicative of trends in sewage disposal practice, have been omitted.

The plants selected for this review, listed approximately in order of completion, are as follows:

1. Washington, D. C.—Sedimentation.
2. New York City (Wards Island)—Activated sludge.
3. Minneapolis-Saint Paul, Minn.—Flocculation, sedimentation, filtration of effluent, chlorination and seasonal chemical precipitation.
4. Buffalo, New York—Sedimentation and chlorination.
5. Cleveland, Ohio (Easterly)—Activated sludge.
6. Sanitary District of Chicago (Southwest)—Activated sludge.
7. Detroit, Michigan—Sedimentation, chlorination.

All plants have mechanically cleaned bar screens except one, which has comminutors. Shredders or grinders are provided for the screenings in all of the other plants except one. However, in one of these plants an alternate method of disposal of unground screenings by incineration with municipal refuse may be used. The shredded or ground screenings are either returned to the sewage or added to the sludge, except in one case, where ground screenings are incinerated.

Grit chambers are used in all cases except at the Chicago Southwest Works. Here provision has been made for the addition of grit chambers if they should be needed. The grit chambers, where used, are in the form of rectangular channels with straight line scrapers, except at Cleveland where square shallow "detroiters" are used. At four of the plants grit is disposed of for fill, and at two the grit is incinerated with dewatered sludge.

All of the plants except two have aerated tanks or channels that serve for flotation of grease which is removed as scum in the sewage settling tanks. All of the plants have mechanical means for removing sludge and scum. Where sludge digestion is used the scum is digested, and in the other cases provision is made for incineration of the scum. Rectangular sewage settling tanks with straight line sludge and scum removal mechanisms are used at four of the plants. Two have circular tanks with revolving mechanisms, and one has square tanks with traction type mechanisms for removing sludge and scum.

Only one of the plants (Saint Paul-Minneapolis) has effluent filters. These are of the downward flow magnetite type.

All three of the activated sludge plants have spiral flow type aeration tanks. At two of the plants circular, radial flow, final settling tanks with revolving sludge removal mechanisms are used. The other uses rectangular tanks with straight line sludge scrapers.

At three plants sludge is digested prior to dewatering, and at Detroit 12½ per cent of the sludge is to be digested. At two of the plants fixed dome roofs are used on the digesters and at the other two floating covers are used. Elutriation of sludge prior to dewatering is provided at one of these plants.

At one plant sludge cake is disposed of as fertilizer or fill, and at four of the plants it is incinerated. At the Chicago Southwest plant the cake is dried and a portion marketed for fertilizer, and the remainder incinerated. At the Wards Island plant the sludge is concentrated and transported to sea for disposal.

At all of the plants provisions are made for odor control to a greater or less extent, as by covering or housing sewage conduits and treatment devices, and conducting foul air

to stacks. At the Wards Island plant special systems are required for control of odors at the sludge storage and concentration tanks and on the sludge vessel.

Methods of sewage treatment and sludge disposal at these plants show considerable variation in trends. The art of sewage treatment and sludge disposal has not yet been standardized, and varying local conditions will continue to dictate some variations in the methods used. The seven plants are described.

T. L. HERRICK

RECTANGULAR TANKS

BY H. D. THATCHER

Civil Engineering and Public Works Review (London), **85**, 167–168 (June, 1940).

In the last ten years much progress has been made in the direction of mechanical desludging of tanks. Scrapers are now available for the whole range of tanks now used in sewage works. This discussion is confined to rectangular tanks and their adaptation to mechanical sludge removal.

The efficient deposition of sludge is brought about by the immediate cessation of kinetic energy, yet many tanks fail to achieve this end. The late Dr. Meider developed a baffle in the form of a Venetian blind in an open position, the whole unit leaning forward in the direction of flow. In combination with v-shaped baffles disposed vertically in front of submerged orifices, remarkable results have been noted, with 80 to 90 per cent of the sludge deposited on a floor area representing 90 minutes detention (15%) in a tank designed for 10 hours detention.

These have scraper mechanisms incorporated in their design, and in all cases have excess activated sludge or humus sludge returned to be handled with the primary sludge. Tests have never shown an Imhoff cone reading of more than 0.5 parts per liter, the average being 0.2.

In some cases in Scotland storm tanks have been eliminated and 12 times D.W.F. are passed through the tanks, and in no case has the Imhoff cone reading exceeded one part per liter in tanks designed on a 12 hour basis.

This authority is so convinced that tanks can play an important part in purification, and that final stages of purification are over-designed, that they recently installed open filter beds, with distributors that can accommodate 3, 6 and 12 times D.W.F.

The incorporation of the scraper mechanism has an important bearing on tank design. It is now accepted that sludge hoppers are constructed immediately beneath the inlet to the tanks to receive the deposited and swept sludge. Later designs provide an inlet and half hopper, the inlet wall being carried down to the apex of the hopper.

There are various types of mechanical scrapers with a carriage incorporated in the design for transferring the sweeping mechanism to succession tanks in parallel.

Another design has a series of " ploughs " extending the full width of the tanks on an endless chain system working continuously.

From a mechanical standpoint the rectangular scraper has much in its favor. It can be lifted entirely out of the tank, and thus presents no surfaces immersed in the sewage. The speed of desludging can be set to accommodate the machine to the lightest deposited sludge. Painting and renewals can be effected without taking the tank out of service. Lastly, one machine can desludge a number of tanks in one day. At one works, under construction, the storm tanks are ahead of the sedimentation tanks and are fitted with a hedge-hopping type of scraper mechanism.

It should be mentioned that this paper is not confined to experiences on large works, several being in the region of a D.W.F. of 600,000 gallons per day.

T. L. HERRICK

BOOK REVIEWS

Sewerage and Sewage Treatment. *Fifth Edition.* By Harold E. Babbitt. Published by John Wiley and Sons, Inc. Price $5.00.

This is an excellent book for class-room use or for the instruction of engineers who desire an up-to-date, well balanced treatise on the problems and progress of sewerage and sewage treatment. If the reviewer is interested in pointing out errors of typography and questionable statements, he can find occasional examples, but these evidences of lack of careful editing need not detract from the outstanding fact that this is a practical, helpful and readable book, with a consistent point-of-view and a commendable simplicity. The total book contains 648 pages, of which only 283 are devoted to sewage treatment and industrial wastes, therefore the material is concentrated to essentials and not overburdened with extensive tables or diffuse references.

The first 298 pages deal with sewage flows, hydraulics of sewers, design of sewer systems, materials, construction, maintenance and use of sewers. These topics are presented clearly and with helpful examples and problems. There is an interesting chapter of 25 pages on sewage and sludge pumping, and a sound discussion of precautions in sewer inspection.

Sewage treatment occupies 14 chapters, operation one chapter, and industrial wastes one chapter of 22 pages, obviously only an outline of this topic. The discussion of objectives in sewage treatment is rather awkwardly handled, and throughout the text there is evidence of none too careful polishing of phrase and sentence. However, an excellent sense of discrimination in the selection and balancing of material leads the reader to overlook such lapses.

The chapter on "Characteristics of Sewage," of 20 pages, is almost too condensed, and contains some rather astonishing statements (p. 322) on the possibility of determining B.O.D. within an hour by means of a mechanical device, which "has found extended use in research work and in the control of activated-sludge plant operation."

The chapter on "The Disposal of Sewage," of 28 pages, is clearly presented, without too much detail on the oxygen balance, but enough to define the relative influences of dilution, reaeration and sludge deposits.

Chapters on screening, grit chambers, sedimentation, chemical treatment, Imhoff tanks, trickling filters, mechanical filters and activated sludge comprise 125 pages. There is a rather unfortunate confusion of settleable solids with suspended solids (p. 373) and Hazen's diagram on settling (p. 376) is somewhat obscure. Information on effluent weir lengths, in a table on p. 388, is quite interesting. Sewage grease can hardly be termed salable, as stated on page 389, even though it is recovered and sold at Bradford. The negligible use of activated carbon in sewage treatment hardly warrants the page (400) devoted to it. With all the data that are available on Imhoff tank operation, it would seem that more representative results should have been selected than those shown for Atlanta in 1913 and 1914, with no B.O.D. data, and nitrates indicated in the effluent.

The chapter on trickling filters is very good, but the section on high-rate filters does not differentiate the "aerofilter" and the "biofilter"; closed filters with forced ventilation are not being extensively developed in Germany (p. 443); the B.O.D.'s of filter influents on page 445 have been misprinted. The sludge from humus tanks is much greater than 2 to 4 cu. ft. per m.g. (page 446).

The chapter on activated sludge is not well organized and is weak on both theory and practice. Novelties are stressed, rather than the sound design and operation of the majority of plants in the United States.

Sludge disposal is well presented, although almost too briefly. Gas utilization is not handled adequately. Comparison of processes provides a short but interesting chapter; operating duties a rather uniquely valuable chapter. There are 18 pages of interesting problems and 381 references. A chapter on industrial wastes is well worth while.

The relatively minor errors that have been mentioned do not detract from the real value of this book, which lies in its direct and practical approach, its consistency of viewpoint, and its elimination of confusing details.

F. W. Mohlman

Sewage Treatment Works. By C. E. Keefer. Published by McGraw-Hill Company. Price, $6.00.

Mr. Keefer's book is written for sewage works operators, who will find in it reference to practically everything that has been published in modern times on the treatment of sewage and the disposal of sewage sludge. The scope of the work is astonishing. It contains 673 pages, 32 chapters, and 841 references, the latter at the ends of the chapters and ranging in number from one reference following the chapter "Cost of Sewage Treatment" to 114 references following the chapter "The Activated Sludge Process." These statistics indicate the great detail and meticulous attention given to quotations from published information. Further, there are 167 figures and 177 tables, many of the latter in considerable detail, with pertinent data arranged in columns, usually graded from minimum to maximum values.

As a reference book for plant operators or sanitary engineers, this work is pre-eminent. It is a veritable encyclopedia of information on sewage works operation. It is so diffuse, however, that it lacks clarity and authority. More discrimination in selection of material would have made it a better text-book or handbook for engineers and chemists who wish to get a clear picture of the theory and practice of sewage disposal.

Types of sewage treatment processes are covered in great detail. The chapter on activated sludge is excellent, also the chapter on sludge dewatering. "Bio-chemistry of Sewage" is inadequately handled in only six pages. "Disposal of Effluents" is weak on the discussion of the oxygen balance, and the book contains practically nothing on stream pollution and reaeration. Also there is very meager information on industrial wastes and their effect on sewage treatment works. The chapter "Sewage Plant Records" is excellent as a guide for the plant operator in sampling, analysis, and recording of data. "Sewage Plant Beautification" (19 pages) may also awaken interest in the more aesthetic phases of a sewage works operator's duties.

The book is so carefully prepared and edited that it approaches perfection from a typographical and editorial standpoint. The inclusion of the results of the years of valuable research at Baltimore, under Mr. Keefer's direction, is one of the pleasing features of the book. It is dedicated to Langdon Pearse, who spent many hours in reviewing the manuscript for the benefit of the author.

F. W. Mohlman

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